U.S. DEPARTMENT OF COMMERCE
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PB-288 548

Development of a Pollutant Monitoring System for Biosphere Reserves

(U.S.) Environmental Monitoring and Support Lab, Las Vegas, NV

Sep 78

United States
Environmental Protection
Agency

Environmental Monitoring
and Support Laboratory
P.O. Box 15027
Las Vegas, NV 89114

EPA-600/4-78-052
September 1978

PB 288548

Research and Development

EPA

Environmental Monitoring Series

Development of a Pollutant Monitoring System for Biosphere Reserves

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SPRINGFIELD, VA. 22161

TECHNICAL REPORT DATA

(Please read Instructions on the reverse before completing)

1. REPORT NO. EPA-600/4-78-052	2.	3. RECIPIENT'S ACCESSION NO. PB288548
4. TITLE AND SUBTITLE DEVELOPMENT OF A POLLUTANT MONITORING SYSTEM FOR INTERNATIONAL BIOSPHERE RESERVES		5. REPORT DATE September 1978
		6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) G. B. Wiersma, K. W. Brown, and A. B. Crockett		8. PERFORMING ORGANIZATION REPORT NO.
9. PERFORMING ORGANIZATION NAME AND ADDRESS Environmental Monitoring and Support Laboratory Office of Research and Development U.S. Environmental Protection Agency Las Vegas, Nevada 89114		10. PROGRAM ELEMENT NO. 1HD620
		11. CONTRACT/GRANT NO.
12. SPONSORING AGENCY NAME AND ADDRESS U.S. Environmental Protection Agency-Las Vegas, NV Office of Research and Development Environmental Monitoring and Support Laboratory Las Vegas, Nevada 89114		13. TYPE OF REPORT AND PERIOD COVERED Final
		14. SPONSORING AGENCY CODE EPA/600/07
15. SUPPLEMENTARY NOTES		

16. ABSTRACT

This report presents an initial approach to identifying and solving the problems of developing a monitoring system for Biosphere Reserves. To date, most proposals have only focused on the selection of Reserves, pollutants to monitor, etc.; the real-world problems of how to monitor and collect and preserve samples and of statistical considerations and the logistics involved, have not been considered. This report attempts to address these problems and proposes specific field work to determine what additional problems may be encountered and what research is still required to enable us to develop a responsive and cost-effective pollutant monitoring program for Biosphere Reserves. Items covered include sample site selection criteria, statistical considerations, pollutant level monitoring techniques suitable to background areas, the development of biological monitors and accumulators and the development and application of pollutant impact monitoring techniques. Quality assurance requirements are also discussed. The above subjects are set in a site-specific framework of Yellowstone National Park and Sequoia-Kings Canyon National Parks.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Environmental biology Site survey Pollution Chemistry	Sequoia-Kings Canyon Yellowstone Biosphere reserves	06F 08G 08H 07B 07C 07D

18. DISTRIBUTION STATEMENT RELEASE TO PUBLIC	19. SECURITY CLASS *(This Report)* UNCLASSIFIED	21. NO. OF PAGES 124
	20. SECURITY CLASS *(This page)* UNCLASSIFIED	22. PRICE PC A06 / A01 MF

EPA Form 2220-1 (Rev. 4-77) PREVIOUS EDITION IS OBSOLETE

EPA-600/4-78-052
September 1978

DEVELOPMENT OF A POLLUTANT MONITORING SYSTEM FOR BIOSPHERE RESERVES

by

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FOREWORD

Protection of the environment requires effective regulatory actions which are based on sound technical and scientific information. This information must include the quantitative description and linking of pollutant sources, transport mechanisms, interactions, and resulting effects on man and his environment. Because of the complexities involved, assessment of specific pollutants in the environment requires a total systems approach which transcends the media of air, water, and land. The Environmental Monitoring and Support Laboratory-Las Vegas contributes to the formation and enhancement of a sound monitoring data base for exposure assessment through programs designed to:

- develop and optimize systems and strategies for monitoring pollutants and their impact on the environment
- demonstrate new monitoring systems and technologies by applying them to fulfill special monitoring needs of the Agency's operating programs

This report presents an initial approach to identifying and solving the problems of developing a monitoring system for Biosphere Reserves. To date, most proposals have focused only on the selection of Reserves, pollutants to monitor, etc.; the real-world problems of how to monitor and collect and preserve samples and of statistical considerations and the logistics involved, have not been considered. This report attempts to address these problems and proposes specific field work to determine what additional problems may be encountered and what research is still required to enable us to develop a responsive and cost-effective pollutant monitoring program for Biosphere Reserves.

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CONTENTS

Page

Foreword iii
List of Figures vii
List of Tables viii
List of Abreviations and Symbols ix
ACKNOWLEDGMENTS x
INTRODUCTION 1
CONCLUSIONS 6
RECOMMENDATIONS FOR FUTURE RESEARCH 7
METHODOLOGY FOR DEVELOPMENT OF A POLLUTANT MONITORING SYSTEM 8
  Preliminary site evaluation using remote sensing techniques 8
  Sampling site selection 9
    Topography 9
    Soil 9
    Continuity 9
    Access 9
    Vegetation types 10
    Sampling site size 10
  Statistical considerations 10
  Pollutant-level monitoring techniques 11
    Soil 13
    Water 13
    Air 15
    Atmospheric deposition 19
    Biological samples 20
    Detection of significant changes in global contamination 20
  Pollutant impact monitoring techniques 22
    Biomass measurements 23
    Long-term indicators of pollutants 23
    Species diversity indices 24
    Microcosms 25
    Bioindicators 28
    Parameters monitored and analytical support 28
  Quality assurance 29
  Biosphere site selection and characterization - examples 32
    Yellowstone National Park 33
      Ownership 33
      Accessibility (Logistics) 33
      Site integrity 35
      Vegetation types 35
      Geology 35
      Soils 37
      Hydrology 44

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CONTENTS (Continued)

Page

  Paleobotany 49
  Meteorology 50

Sequoia-Kings Canyon National Parks 52
  Ownership 52
  Accessibility 54
  Site integrity 54
  Vegetation types 55
  Geology 59
  Soils 63
  Hydrology 65
  Paleobotany 69
  Meteorology 69

REFERENCES 74
APPENDIX A. METRIC CONVERSION TABLE 81
APPENDIX B. SPECIES LIST--YELLOWSTONE NATIONAL PARK 82
APPENDIX C. SPECIES LIST--SEQUOIA AND KINGS CANYON NATIONAL PARKS 102

LIST OF FIGURES

Number		Page
1	Plot of Coefficients of Variation Versus Sampling Error and Required Number of Samples	12
2	Map of Yellowstone National Park	34
3	Outline of the Yellowstone Caldera	39
4	Extent of Ice in Yellowstone National Park	42
5	Soil Associations in Yellowstone National Park	44
6	Kings River Watershed	53
7	Records Available at Selected Stream Gauging Stations in the Kings River Basin	71
8	Wet and Dry Periods in the Runoff of Kings River at Piedra	72

LIST OF TABLES

Number		Page
1	Lead and Zinc Residue Levels in Organic Soil Horizons	14
2	Average Coefficients of Variation for Stream Parameters in Yellowstone National Park	17
3	Mercury Residues in Fish and Water	21
4	Suggested List of Parameters to be Monitored and Considered for Biosphere Reserve Sampling Sites	29
5	Volatile Organics in Groundwater from Well #5 Prior to in situ Coal Gasification	31
6	Climatological Data by Months for Stations Representing Basal Elevations In and Near Yellowstone Park	51
7	Summary of Mineral Compositions of the Plutonic Rocks	62
8	Kings River Investigation Annual Discharge of Kings River at Piedra	66
9	Kings River Investigation Variability in Observed Hydrologic Data by Season	68
10	Kings River Basin Gauging Stations	70
11	Climatic Data at Ash Mountain and Giant Forest--1964	73

LIST OF ABBREVIATIONS AND SYMBOLS

AF -- acre feet

Avg -- average

BOD -- biochemical oxygen demand

CV -- coefficient of variation

DO -- dissolved oxygen

EMSL-LV -- Environmental Monitoring and Support Laboratory-Las Vegas

GEMS -- Global Environmental Monitoring System

GNEM -- Global Network for Environmental Monitoring

MAB -- Man and the Biosphere

ppm -- parts per million

RTG -- Radioisotope Thermoelectric Generator

SCEP -- Study of Critical Environmental Problems

SCOPE -- Scientific Committee on Problems of the Environment

TKN -- Total Kjeldahl Nitrogen

UN -- United Nations

USGS -- U.S. Geological Survey

USDA -- U.S. Department of Agriculture

ACKNOWLEDGMENTS

The air monitoring section of this paper was prepared by Mr. Robert Snelling of the Monitoring Operations Division, Environmental Monitoring and Support Laboratory-Las Vegas. We sincerely appreciate his efforts in support of this project.

INTRODUCTION

Man's impact on the environment has had a far-reaching and at times catastrophic effect. Long gone are the days when the pollution caused by man impacted only his immediate surroundings. Today, pollution problems are truly global in nature, and transcend any or all national or political boundaries.

A considerable body of literature exists describing the global transport of pollutants. A few of these reports are reviewed below to exemplify the existing literature.

Elgmork et al. (1973) reported that the snow in Norway was polluted. They found levels of lead up to 98 micrograms per liter, sulphur levels of 8.5 milligrams per liter, and pH as low as 3.25. The three study areas were too remote to be polluted from local sources, nor could Norwegian industries or automobiles be attributed as the causes of the polluted snow. Consequently, Elgmork et al. concluded that the polluted snow resulted from air masses bringing pollution in by low pressure systems from the great industrial and urban areas of western and central Europe. A related study by Johnson et al. (1972) showed that several streams in New England were acidified primarily as the result of sulfur pollution being washed out of the air by rain. This atmospheric sulphur pollution originated mainly from the combustion of fossil fuels from large industrial centers of the eastern and central United States, and could not be attributed to local sources of pollution. Another study by Schlesinger et al. (1974) found that significant amounts of lead, cadmium and mercury were present in bulk precipitation on Mt. Moosilauke in New Hampshire. They determined that some of the low pressure system tracks in North America converged on the northern New England states and winds coming from the large population and industrial regions of the central and mid-Atlantic regions of the United States brought in air pollution to this remote area.

Lazarus et al. (1970) reported on the results of a nationwide precipitation network. They found detectable concentrations of lead, zinc, copper, iron, nickel, and manganese. They implicated human activities as the primary sources of these elements in the rain water. They also found that the highest overall concentrations were in the rain samples collected in the northeastern United States. In addition, a positive statistical correlation was found between the lead concentration at each sample station and the quantity of gasoline sold in the vicinity of each station.

Chow and Earl (1970) studied airborne lead in the vicinity of San Diego and found that only a fraction of the lead in air is precipitated out near the source of emission. They surmised that the remainder of the lead aerosols was transported by major air currents around the globe. A study by Hirao and Patterson (1974) supported this analysis. The latter study of lead levels was made in Thompson Canyon, a remote site on the high Sierra Crest. According to their data, about 16 kilograms of lead were deposited each year in this 14-square-kilometer watershed. They further determined that 97% of this lead was from anthropogenic sources. They stated:

> "These findings show that a widespread assumption, that lead pollution is mainly confined to urban complexes and is essentially absent in open county, is improbable. . . ."

Other elements have been shown to be transported on a global basis. For instance, Weiss et al. (1971) sampled the Greenland ice cap. Their data on mercury levels are illustrative of a possible buildup of mercury in the ice sheet in recent times. For example, in samples representing deposition prior to 1952[1], the mean mercury concentration was 60 ± 17 nanograms per kilogram of water. Samples representing deposition from 1952 to 1965 had a mean concentration of 125 ± 52 nanograms per kilogram of water.

Zoller et al. (1974) analyzed atmospheric particulate material at the South Pole for 22 elements. They found antimony, lead, selenium, and bromine; all of these elements were highly enriched over what could be expected from earth crustal values. They postulated that these elevated levels primarily resulted from the high-temperature combustion sources, either natural volcanoes or man-made fossil fuel burning.

Global transport has also been confirmed in organic pollutants such as the insecticide DDT. For example, Anas and Wilson (1970) reported that nursing northern fur seal pups collected on the Pribilof Islands in 1969 contained DDT and its isomers in both the pup's fat tissue and the mother's milk.

Concern over widespread global contamination resulting from man's activities has been one of the driving forces behind the attempt to establish a global network for biosphere reserve sites. The Study of Critical Environmental Problems (SCEP) Report (Massachusetts Institute of Technology, 1970) stated:

> "Over the past few years, the concept of the earth as a 'spaceship' has provided many people with an awareness of the finite resources and the complex natural relationships on which man depends for his survival. These realizations have been accompanied by concerns about the impacts that man's activities are having on the global environment. Some concerned individuals, including well-known scientists, have warned of both imminent and potential global environmental catastrophes. . . ."

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[1] Except for one sample collected in 1946, all of the samples in this group were deposited prior to 1900.

The task of estimating the extent and the magnitude of man's impact on the global environment is challenging. This task was articulated by Morgan et al. (1975) who stated:

> "Man's technological advances and increasing population have caused a significant impact on our environment. We are now faced with the arduous task of describing on a global basis, those factors that impinge on environmental quality. This information is needed by both the researcher and the official who must not only assess environmental quality but also control emissions into all aspects of the environment. . . ."

There has been a tremendous amount of discussion, meetings, and thought given to a Global Environmental Monitoring System (GEMS). A variety of organizations and committees, including but not limited to the U.S. International Task Force of the Global Network for Environmental Monitoring, the Global Monitoring Task Force of Scientific Committee On Problems of the Environment (SCOPE), the Man and Biosphere Expert Panel on Pollution, the Study of SCEP, Task Force II--Committee on International Environmental Affairs, and the SCOPE Commission on Environmental Monitoring and Assessment, have called for the formation of such a global monitoring network. The criteria and needs for biosphere reserves have been described in general in a variety of reports, such as the Report of the Ad Hoc Task Force on Global Network for Environmental Monitoring (Ad Hoc Task Force on GNEM, 1970), and the SCOPE Report 3 (Munn, 1973).

The United Nations (UN) Conference on Human Environment (Man and Biosphere, 1974) which was held in Stockholm in June 1972 recommended the establishment of the United Nations Environment Program. In conjunction, it recommended the establishment of EARTHWATCH, which has a four-pronged program including monitoring, research, evaluation, and information exchange. The ultimate objective was the establishment of GEMS. The seven program objectives of GEMS are:

1. An expanded human health warning system
2. An assessment of global atmospheric pollution and its impact on climate
3. An assessment of the extent and distribution of contaminants in biological systems, particularly food chains
4. An improved international disaster warning system
5. An assessment of the state of ocean pollution and its impact on marine ecosystems
6. An assessment of the response of terrestrial ecosystems to environmental pressures
7. An assessment of critical problems arising from agricultural and land use practices.

As part of this global environmental monitoring system, it has been recommended that biosphere reserves be established. For example, the UN Conference on the Environment, 1972, recommended that biological reserves be established within the framework of the Man and Biosphere Program (MAB) (Man and Biosphere, 1974). The report titled "Man's Impact on the Global Environment" (Massachusetts Institute of Technology, 1970) recommended similar type entities, calling them ecological baseline stations in remote areas or biosphere reserves. Biosphere reserves may be defined as relatively pristine areas which represent the major natural ecosystems of the earth and have been set aside for study and preservation. The value of these reserves to a global environmental monitoring system is considerable. These biosphere reserves will benefit a global environmental monitoring system in the following ways:

1. They will provide protected ecosystems which are relatively free of the effects of man's activities.
2. They will provide a source for obtaining background data on pollutant levels.
3. They will serve as early warning sites for monitoring global pollution trends.
4. They will serve as natural repositories of genetic pools for studying and preserving indigenous animal and plant species.

Franklin (1977) lists several kinds of research and monitoring programs which the reserves will be used for. These include:

1. Long-term baseline studies of environmental and biologic features
2. Research to help develop management policies for the reserves
3. Experimental or manipulative investigations (outside strictly preserved areas) particularly on the ecological effects of human activities
4. Environmental monitoring, including use as part of the GEMS system
5. Study site for the various MAB research projects.

This paper is concerned principally with item four. We intend to discuss how to develop an accurate and cost-effective pollutant monitoring strategy that can be applied across a spectrum of biosphere reserves.

Environmental monitoring is defined as the systematic collection of physical, chemical, biological, and related data pertaining to environmental quality, pollution sources, and other factors that influence or are influenced by environmental quality. Environmental quality data are essential for determining the exposure of critical populations at risk. Such data are obtained by identifying and measuring pollutants and their concentrations in air, water, vegetation, soil, and food. Environmental exposure monitoring must take into account acute or chronic effects resulting from short-term acute exposures as well as low-level chronic exposures to one or more pollutants. In addition, the possibility that a single pollutant may cause or contribute to the aggravation of several different environmental effects must be considered. The identification and measurement of pollutants in preserved areas, such as the biosphere reserves, may permit the monitoring of subtle deleterious processes which may be masked in areas of high impact. In identifying and measuring the exposure of receptor communities to chemical or physical agents, monitoring data must provide the basis for quantitating the contributions of every environmental pathway for each chemical or physical form of the pollutant. This includes the monitoring of air, water, soil, plants, animals, and microorganisms which can indicate levels, patterns, and trends of environmental pollutants or their metabolites. The health, growth, and number of plants or their accumulation of a pollutant may be a useful indicator or early warning of environmental contamination that may adversely affect human health.

This paper is a detailed analysis of the potential problems associated with monitoring a biosphere reserve and it is a follow up to a previous paper by Morgan et al. (1976). It essentially analyzes the background characteristics of two "types" of biosphere reserves which were suggested by Franklin (1976, 1977) and are used as examples for discussion purposes. These sites were selected because they have a relatively good mix of vegetative types and water systems, and possess relatively large areas that are remote from man. Even Yellowstone National Park, as heavily visited as it is, has extremely remote and relatively unvisited areas. In this paper, the applicable monitoring techniques are reviewed and a plan for developing an accurate and cost-effective pollutant monitoring system for biosphere reserves is presented.

The reserves selected for discussion in this paper are Yellowstone and Sequoia-Kings Canyon National Parks. This is not to imply that these sites will be chosen for initial studies, but they were chosen because it is easier to conceptualize many of the problems attendant with monitoring biosphere reserves when specific cases are considered. In addition, the preparation of a monitoring scheme for any biosphere reserve requires a detailed analysis of the background environmental factors, both physical and biological, which characterize a site. Such characterizations would be necessary for other biosphere reserves prior to the initiation of pollutant monitoring systems. Rather than merely listing parameters to be investigated, we found it much more instructive to attempt to discover what each of the characteristic parameters was, and describe it as fully as practicable, as if a monitoring program were going to be initiated at each site.

What follows is how we intend to conduct a study to develop a cost-effective and environmentally responsive pollutant monitoring system for these biosphere reserves.

CONCLUSIONS

1. In general, the establishment of a cost-effective and accurate pollutant monitoring system is a critical need in the overall development of the Biosphere Reserve Program.

2. A preliminary methodology study conducted on a limited number of biosphere reserve sites is the best approach to the ultimate development of a uniform, efficient, and cost-effective pollutant monitoring program.

3. The U.S. Environmental Protection Agency should develop biosphere reserve monitoring systems.

4. A variety of Federal agencies should operate the monitoring network.

5. Analysis of available background information for the two subject biosphere reserves has indicated that our development project should take place on reserves for which more extensive background information is available. These would probably be experimental forests or National Parks for which there is a closely associated experimental forest. An example is Great Smoky Mountains National Park which is closely related to Coweeta Experimental Forest. Both are identified biosphere reserve sites.

RECOMMENDATIONS FOR FUTURE RESEARCH

1. The U.S. Environmental Protection Agency should fund a monitoring methodology development study to determine the best and most efficient way of monitoring pollutants in a biosphere reserve.

2. This study should begin as soon as possible.

3. The study should be limited in scope the first year to two biosphere reserve sites and expand to four sites in subsequent years.

4. The development program should be planned for a 3- to 5-year period with intermediate results being disseminated as soon as possible.

5. Planning should begin concurrently with this methodology study, with the goal of full implementation of a monitoring program in 5 years for the Biosphere Reserve Program.

METHODOLOGY FOR DEVELOPMENT OF A POLLUTANT MONITORING SYSTEM

PRELIMINARY SITE EVALUATION USING REMOTE SENSING TECHNIQUES

Before actual biosphere site visits are undertaken, every effort will be made to obtain all available photographic imagery. The first types of photos obtained will be photos from the Landsat One and Landsat Two satellites (Landsat One was originally ERTS-1 and now is renamed) (USGS, 1975). Each Landsat satellite can cover most of the Earth with repetitive coverage approximately every 18 days. The Landsat satellites provide four spectral bands which are:

a. Band 4 - 0.5 to 0.6 micrometers, emphasizes movements of sediment in water and areas of shallow water.
b. Band 5 - 0.6 to 0.7 micrometers, emphasizes cultural features.
c. Band 6 - 0.7 to 0.8 micrometers, emphasizes vegetation, the boundary between land and water, and land forms.
d. Band 7 - 0.8 to 1.1 micrometers, provides the best penetration of atmospheric haze and emphasizes the boundary between land and water, land forms, and vegetation.

Black and white photographs for Sequoia-Kings Canyon and Yellowstone National Parks in bands 5 and 7 and a composite false-color photograph for both areas combining bands 5, 6, and 7 have been obtained. Since the individual multispectral picture images are approximately 185 kilometers on the side, the actual national park areas were delineated and then blown up to 91-cm × 91-cm size. The blow-ups are on bands 5 and 7.

There is much precedence in the literature for photographic assessment of environmental conditions (Douglas et al., 1972; Meyer et al., 1971; Shay, 1970). According to the best information available at present, adequate high resolution, high altitude photographs are not available for the two subject biosphere sites, Yellowstone National Park and Sequoia-Kings Canyon National Parks. However, good quality aerial photographs are available for both Sequoia-Kings Canyon and Yellowstone National Parks at lower altitudes ranging from 3,000 to 12,000 meters. These photos are available through the U.S. Forest Service for the Sequoia-Kings Canyon area, and the U.S. Geological Survey can supply them for Yellowstone National Park. This information should be obtained when the approximate areas within the national parks which are going to be candidate selection sites for actual field sampling work are identified. It is expected that the photography used will include color, high resolution black and white, and infrared imagery.

SAMPLING SITE SELECTION

For biosphere reserves the size of Yellowstone National Park and the Sequoia-Kings Canyon National Parks or most of the other 27 proposed biosphere reserves, it would not be feasible nor is it recommended that the entire National Park or experimental forest be sampled. Small, predetermined, and isolated units within each area would be designated as sampling sites. What follows is a list of the criteria to be used in the selection of the specific location within each of the biosphere reserves for the sampling site.

To be consistent and minimize confusion, the following terminology will be used throughout this paper:

Biosphere Reserve Site: The overall reserve such as Yellowstone National Park or Sequoia-Kings Canyon National Parks.

Sampling Site: The unit within the biosphere reserve on which sampling data will be carried out.

Sampling Point: The actual point of sampling.

Topography

The sampling sites will be selected which have a minimum slope, minimum breaks in the terrain, and minimum changes in elevation. The terrain features should be relatively smooth with no abrupt breaks such as would be made by ravines, small canyons, washes, and so forth. The local plant and animal communities will also be prime determinants in making a sampling site selection.

The elevation of the sampling sites will be determined by the geographical characteristics of the biosphere reserve involved. In the Yellowstone National Park and the Sequoia-Kings Canyon National Parks sampling sites selected will probably be above 2,400 meters in elevation, but below the tree line--unless specific sampling sites are desired within specialized biological communities such as the tundra, as strongly recommended by Reiners et al. (1975).

Soil

The soil type should be as uniform as possible, balanced against other required factors.

Continuity

The actual sampling site should lie within a vegetation type of a continuous nature. It is suggested that the sampling site should be in an area of a continuous vegetation type of similar physiographic aspect, slope, and altitude and that the area be of a size sufficient to enclose the sampling site and minimize edge effects.

Access

The sampling site must be remote enough to prevent inordinate access by the curious. The normal, occasional use by man that the sampling site historically has been exposed to should continue. However, it must be reachable by either mechanical or foot transportation; therefore, balance has to be established between remoteness and proximity to a trail or landing pad for a helicopter.

Vegetation types

On each sampling site, samples will be collected from three basic vegetation types. Each sample type would be located in a stable community or climax for the particular area being considered. Examples of three vegetation types that may be chosen on the subject biosphere reserves are mixed conifer, shrubland, and meadow complex.

Sampling site size

A sampling site of one square kilometer would generally be adequate. The size, however, should be varied to fit various terrain features and also to be consistent with homogeneity and vegetation type. For example, a meadow could be smaller than a square kilometer whereas, a site of a mature mixed conifer forest would probably have to be at least a kilometer square in size. Final sampling site selection must be accomplished in the field.

Permanent corner stakes would be established and their locations tied to prominent terrain features and plotted on topographic maps. Corner stakes would consist of a steel pipe approximately 2 to 5 centimeters in diameter and 1.5 meters in length driven into the ground to a depth of at least 0.5 meters. The pipe would be painted with blaze orange paint. To prevent drawing unnecessary attention to the area, no other markings would be placed on the pipes. All samplings from this point on would be tied to one or the other of the established corner pipes. If, because of terrain features or vegetation characteristics, the sampling site is neither a square nor a rectangle, additional pipes would be established to mark the exact outer limits of the sampling site.

The selection of sampling points would be based on a systematic sampling pattern in accordance with the techniques recommended in statistics books such as those by Snedecor and Cochran (1967). The initial starting point, however, would be a randomized point with the overlaying systematic grid then being laid off from this randomized point.

Sampling points lying in a systematic pattern can be easily delineated on a map and located in the field with chain and compass techniques. Since the individual sampling sites should be relatively homogeneous, the estimate of variation by random sampling versus systematic sampling should be similar. Under less homogeneous conditions, systematic sampling provides better estimates of the mean and variation (Husch, 1963). Sampling error for the presample would be computed as for a random sample. As Osborne (1942) has shown, the resultant sampling error calculated in this manner estimates the maximum sampling error.

STATISTICAL CONSIDERATIONS

One of the principal objectives of the Biosphere Reserve Monitoring Program would be to detect long-term accumulation (changes in levels) of pollutants on each of the biosphere sites. Therefore, a logical extension of this is that sampling designs must be sensitive enough to determine small differences in levels within a given time frame. This raises the immediate question of how many samples are required for each set of pollutants in each environmental media sampled to be able to tell the difference between different time periods. At another level of analysis, differences in pollutant levels between biosphere reserves are evaluated; however, this would not take precedence over determining our sampling numbers to show differences with time. The question then becomes which time frame would be most desirable to detect differences between biosphere reserve sites. Annual sampling and annual changes are the most commonly used time periods to measure differences and trends. However, considering the extensive variability inherent in natural areas, the state-of-the-art of our analytical capabilities and the relatively low levels of pollutant concentrations to be expected in these areas, it may not be possible to attempt to differentiate between 1-year intervals.

The primary considerations in determining how many samples are required to make certain levels of determination are:

1. The required level of precision of your estimate
2. An estimate or the actual variability of the particular parameter being measured

In this project, differences of plus or minus 10% at the 95% confidence interval should be detected. To calculate the estimated number of samples to achieve this precision, an estimate of the variability existing on each of the biosphere sites must be made. Thus presamples would be collected prior to any intensive sampling. Once estimates of variability are obtained for every pollutant in every area in every media, then the number of samples required to achieve this error can be calculated.

If we arrive at a reasonable number of samples, we can then proceed to an intensive sampling program. Far more likely, however, is the situation of the flat portion of the curve as shown in Figure 1. In other words, it would take a tremendous increase in samples to achieve a relatively small increase in precision. Since it is rather obvious that a controlling factor in making the biosphere monitoring program cost-effective would be the analytical cost, we must limit ourselves to a reasonable number of samples. Therefore, it may be impossible to achieve the level of precision on a year-to-year basis because the expected difference between years falls within the sampling error. It may then become necessary to go to longer time intervals between sampling.

In the presample, it is estimated that approximately 15 to 20 samples in each media (soils, water, and various types of vegetation) would be collected.

This preceding discussion deals primarily with the variability of pollutant levels in the various media. Other types of sampling programs are envi-

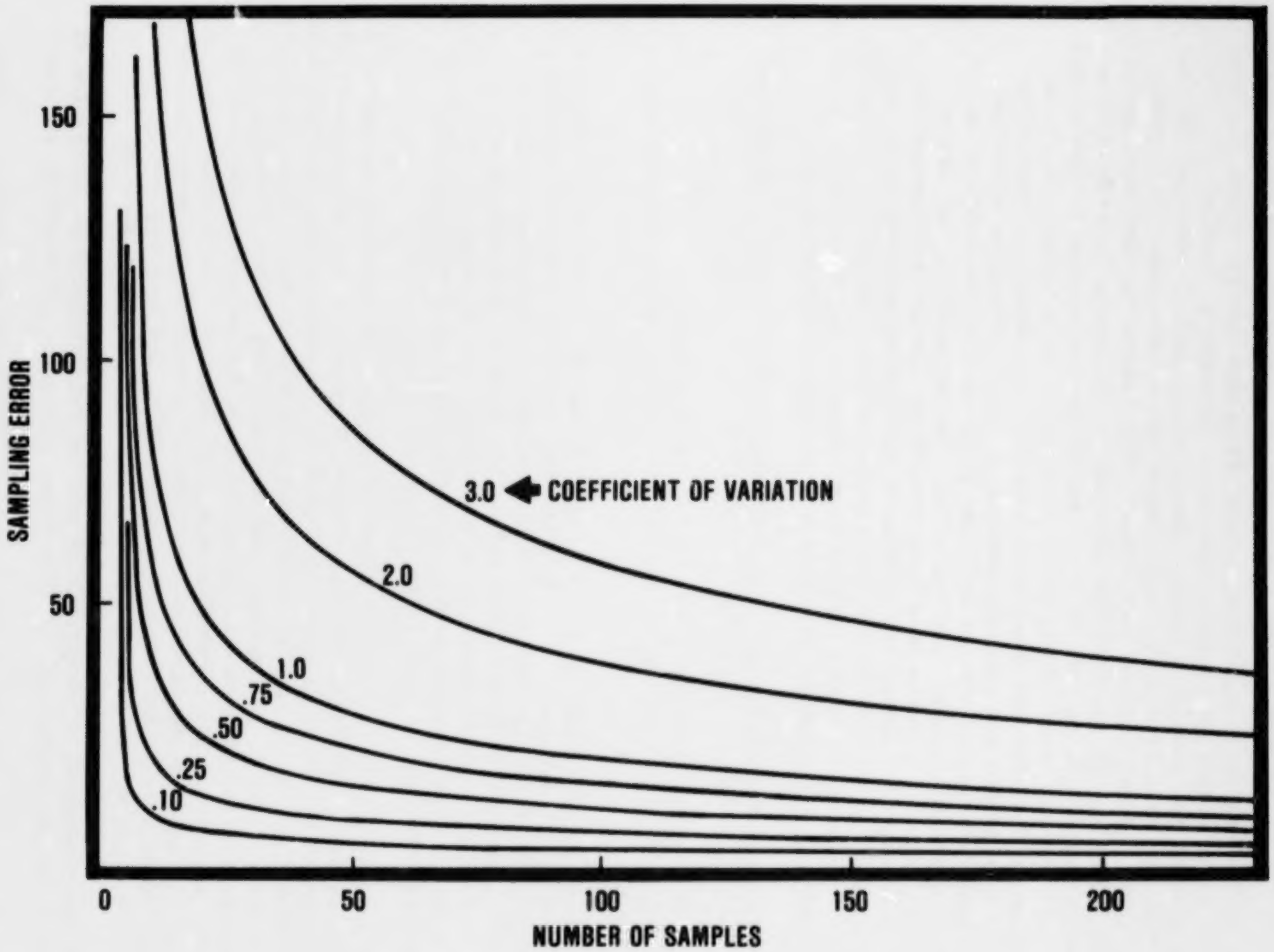

Figure 1. Plot of coefficients of variation versus sampling error and required number of samples.

sioned: for example, the use of an electronic capacitance herbage meter for estimating biomass. There is an entirely different set of variability parameters associated with this instrument which are totally divorced from the variability that can be expected from pollutant levels. Again, presampling would be required to determine the number of samples that would provide the desired level of precision. Similar considerations would apply to other measurement techniques described in this paper.

In terms of an overall statistical design for analyzing and assessing changes in various pollutants, it would seem reasonable that data from each year's sampling be considered one block in an analysis of variance experiment. A two-way classification should be able to simultaneously determine if there are significant differences among years and among sites.

POLLUTANT-LEVEL MONITORING TECHNIQUES

A presampling of each sampling site would be required to obtain the information needed to produce a statistically valid and economically feasible sampling scheme. The procedures set forth here are somewhat general, but are aimed at the probable conditions to be encountered in the two biosphere reserves, Yellowstone National Park and Sequoia-Kings Canyon National Parks, which have been chosen as test case sites. A more specific sampling plan would be formulated after presampling.

The data required prior to the design of the final sampling plan includes the size and shape of the sampling site, the media available for sampling, and the variability of residue levels within the media selected for monitoring.

Soil

A rough estimate of variability can sometimes be made by extrapolation from similar data. A study by Reiners et al. (1975) was conducted on the levels of lead (Pb) and zinc (Zn) in coniferous forest soils at high elevations. The number of samples required can be estimated using the coefficients of variation (Table 1) for the fir, krummholz, and tundra data and the plot of the sampling error versus the coefficient of variation (Figure 1). The mean Pb or Zn levels (dry/wet) at each sampling site within a vegetation type were used. Coefficients were calculated for the litter, fermentation layer, humus, and total organic samples combined. For example, using the calculated coefficient of lead for the three vegetation zones sampled and using Figure 1, it can be estimated that for a desired 10% sampling error with a 95% probability, it will be necessary to collect from 30 to about 65 samples.

The above estimate of the required number of samples can probably be considered a maximum since the selection criteria for terrestrial sampling sites were chosen to minimize variations within each site. It can reasonably be expected that the variation within a sampling site (variation between sampling points) would be lower and thus reduce the required number of samples. Using this assumption, the presampling will consist of approximately 20 sampling points within each sampling site. The samples collected should provide sufficient information to design a suitable sampling plan.

TABLE 1. LEAD AND ZINC RESIDUE LEVELS IN ORGANIC SOIL HORIZONS*

Vegetation Type	Number of Sites	Mean ppm Pb	Coefficient of Variation Between Sites	Mean ppm Zn	Coefficient of Variation Between Sites
Fir	5	145	0.27	90	0.24
Krummholz	4	120	0.36	73	0.43
Tundra	5	38	0.40	29	0.23

*(Reiners et al., 1975)

The sampling point grid will be established by chain and compass techniques and a 20-meter transit would be established. A 5-centimeter diameter core of the organic and inorganic layers would be collected at odd meter intervals (10 subsamples) and composited by layer (litter, fermentation, and humus) in a "clean" (polychlorinated biphenyls (PCB)-phthalate free) plastic bag. After thorough mixing, 1-pint and ½-pint samples will be placed in Teflon-lined cans. Prior to sealing of the cans, the samples would be air dried, if necessary. The sampling scheme has been designed to detect changes in pollutant concentration, not to determine the total insult on an area basis. A description of each sampling point would also be recorded, including information on slope, aspect, vegetation, soil characteristics, samples, etc.

In presampling, an attempt would be made to collect samples from all three organic soil layers for analyses and a mineral soil sample. The final design would probably be limited to only one organic sample (one layer or total) and a mineral soil sample. (There may be insufficient litter for an adequate sample in certain locations, so all three layers may be composited.) The samples would be cooled as soon as practical.

A sampling code would be developed. The basic code would include the following items. A code number would be assigned for each biosphere reserve. For example, Yellowstone National Park could be "A" and Sequoia-Kings Canyon National Parks could be "B". The next item in the code number would identify the actual sampling site location. This would be numbered consecutively through whatever number is necessary and keyed to the actual map location for the appropriate biosphere reserve. The third letter would represent the type of sample, i.e., S = soil, W = water, etc. However, this sampling marking section would probably be a two-digit unit because it would be required to make distinctions between various types of soil samples. For example, 1 and 2 designations would be necessary for different depths of soil. The next number in the code would represent the actual sampling site number. Finally the last four digits would represent the month of sampling and the year respectively.

Duplicate samples would be collected at random from 50% of the field composites. These duplicates would provide an estimate of the combined errors due to subsampling, extraction, and analysis. All samples of a given type would be considered to be from the same population.

Analytical methods for soils are not standardized but a technique employing total digestion would probably be used. Dry ashing as used by Reiners et al. (1975) or a complete wet digestion using nitric acid-hydrogen peroxide-hydrofloric acid or perchloric acid could also be employed. Mercury would be determined following the EPA (1974) method. A possible method for extraction of arsenic uses nitric-perchloric acid (Wauchote, 1976). Several procedures for analyses of chlorinated hydrocarbons and polychlorinated biphenyls exist.

It has been recommended by Morgan et al. (1976), the Ad Hoc Task Force on GNEM (1970), and the SCOPE report (Munn, 1973), that chloride, phosphorus, and nitrogen also be determined in soils. Data on chlorides collected by Eriksson (1952) indicate that natural chloride deposition rates of 11 to 35 pounds per acre per year are common and rates as high as 100 pounds or more are not unusual near the coast. Chloride is aerially transported inland from the sea and deposited by rain (Eaton, 1966). The probability of detecting a significant change in chloride residue levels and being able to attribute this to man's activities seems remote. The levels in soil are naturally high, there is a constant substantial natural influx, and finally chlorides are easily leached from soils.

Nitrogen and phosphorus are plant nutrients common to soil and organic matter. They are not typical of global-type air pollutants that would be deposited in remote areas. An increase in residue levels could result from the destruction of living tissue on the site, but there are better methods for detecting decadence. Terrestrial nitrogen fixation greatly exceeds the amount of nitrogen oxides released as an air pollutant. The complexities of nitrogen dynamics in soil make it impractical to monitor global nitrogen oxide contamination by monitoring soils.

Phosphorus is a relatively rare element compared to nitrogen and has been indicted in water pollution. It is not generally thought to be an air pollutant nor does it enter the atmosphere as part of the phosphorus cycle.

The basic objective of this monitoring system is to estimate and keep track of pollutant levels and certain measurable pollutant effects on each of the biosphere reserves. For this reason and because of the discussion above, no proposal is made to monitor for nitrogen, phosphorus, or chlorides on each biosphere reserve. Studies of perturbations of nutrient cycling are important, however, and will be included in future study proposals.

Water

The selection criteria for a water monitoring site are different than those for terrestrial monitoring. A water sample including its constituents is a product of an entire watershed so the aquatic biosphere site will encompass an entire watershed. The watershed will have to be as undisturbed by man as possible, i.e., no campgrounds, no roads or areas of other concentrated human activities, and no unusual natural inputs of contaminants such as geysers, fumaroles, volcanoes, etc. The site must also be assured of remaining free of man's interference to ensure that any changes detected are a result of only regional or global contamination.

The procedure for sampling water varies from simple dip or grab samples to the sampling of several vertical profiles at equal discharge increments for flowing water, or multiple points on a 3-dimensional grid for impoundments (Feltz and Culbertson, 1972). Water sampling in Sequoia-Kings Canyon and Yellowstone National Parks will probably be limited to small streams. Sophisticated sampling procedures would be employed if appropriate--although dip samples should suffice for small clean mountain streams.

Residues in water pose an additional sampling problem compared with soil or vegetation. Levels of residues can change rapidly due to changes in stream flow. Thus, it is necessary to determine stream flow, turbidity, and non-filterable residues when collecting water samples for residue data analyses.

The preliminary sampling would entail collection of about 20 water samples, each on a different day, and analyzing for total arsenic, cadmium, mercury, lead, and certain organics. At the time of sampling, the flow rate would be recorded, and the samples would be collected for determination of turbidity and non-filterable residues. It has been suggested by Morgan et al. (1976) that the following pollutants should also be considered for monitoring in water: turbidity, chlorides, BOD, DO, coliform bacteria, phosphorus, and nitrogen. However, attempts would not be made to detect changes in all these parameters as a measure of man's global impact.

Turbidity is an optical measure of suspended matter in water samples. In an undisturbed watershed it is related to flow and may vary seasonally due to the source of water and organic matter content. Man typically increases turbidity by physical disruption of the watershed or by direct input, either of which would invalidate the watershed as a sampling site. Changes in turbidity might be detected if global or regional contamination were sufficient to cause decadance of the watershed thus leading to increased erosion. However, this would be a very indirect and insensitive measure of global contamination.

Chloride is found in all natural waters but is typically associated as a pollutant with sewage and irrigation waters. The analysis for chloride is simple, precise, and routine--although its value as a measure of global contamination is questionable. Chloride in water is naturally derived from sedimentary and igneous rocks, and there is a natural aerial input from the oceans. Chloride fall-out or rain-out due to man's activities is usually not considered a significant global pollution threat. In addition, the probability of detecting significant man-caused changes in chloride levels is quite remote. The EPA's (1972) data on the water quality of Yellowstone National Park indicates that there is considerable variation in the chloride levels of streams. The coefficient of variation of chloride can be rather high. From Table 2, it can be seen that the overall coefficient of variation for streams in Yellowstone National Park is 0.72. Using Figure 1 to achieve a 10% sampling error for chloride would require over 200 samples. Chloride determination in rainwater or snowfall would be a much more reasonable approach.

TABLE 2. AVERAGE COEFFICIENTS OF VARIATION FOR STREAM PARAMETERS IN YELLOWSTONE NATIONAL PARK (EPA, 1972)

PARAMETER	NUMBER OF STREAMS	MEAN C.V.
Water Temperature	33	0.50
Turbidity	34	1.04
Conductivity	36	0.26
Dissolved Oxygen	33	0.08
pH	36	0.04
Total Residue	33	0.31
Ammonia	34	0.88
TKN	34	0.81
Nitrite + Nitrate	34	1.01
Fecal Coliform	29	1.22
Total Phosphorus	36	0.81
BOD - 5-Day	27	0.28
Chloride	36	0.72

The biochemical oxygen demand test is designed to determine the relative oxygen demand of waste waters, effluents, and polluted waters (Standard Methods, 1971). Since it is assumed that there would be no wastewater discharges in the biosphere reserve watershed only a significant perturbation of the ecosystem could cause an increase in the BOD. The attempt to detect ecosystem disturbance through the use of BOD is again an awkward and indirect method. The same basic argument holds for nitrogen and phosphorus determinations. The input of nitrogen to the ecosystem through the conversion of NO_x is insignificant compared to nitrogen fixation and natural atmospheric input. Enormous amounts of data would have to be collected to detect a significant change of the nitrogen content of the water and then be able to relate this to man's output of NO_x. The phosphorus cycle has no aerial or gaseous phase so significant aerial transport of phosphorus seems unlikely. As a measure of ecosystem perturbation, the phosphorous cycle is indirect and probably insensitive. If changes in BOD, phosphorus, nitrogen, and chloride level were detected, a great deal of additional data would be required to determine the reason for the changes. These data may not even be available given the present state of measurement methodologies.

The amount of dissolved oxygen in water is of concern when the level is reduced to the extent that it becomes critical to aquatic life. Levels in the turbulent flowing streams of Yellowstone National Park are typically at or above the saturation level. An increase in global or regional contamination would have no direct effect on dissolved oxygen.

Coliform or fecal coliform bacteria were also recommended for monitoring on biosphere reserves. Fecal coliform bacteria are normal inhabitants of mammalian digestive tracts. On a sampling site there is a minimum of human activity so the coliform densities would reflect recent fecal contamination by endemic mammals. Fecal coliform bacteria are not generally considered an air pollutant. Since man would not be directly contaminating the reserve either locally or regionally, the value of this parameter is also questionable. Bacteria counts would not be used to assess man's contamination of the global environment. Any change would be due to local contamination.

In addition to the above discussion a look at Table 2 and Figure 1 shows that certain of the parameters mentioned above would require relatively large numbers of samples to meet a ± 10% sampling error. For example, coliform bacteria were measured in 29 streams in Yellowstone National Park. The coefficient of variation was 1.22, and using Figure 1, this would give an estimated number of samples required for a 10% sampling error well in excess of 220 samples.

One-gallon water samples for chlorinated hydrocarbon analysis would be collected in a glass bottle with Teflon-lined screw caps. All glassware used in the collection of samples would be thoroughly washed, rinsed, and heated to destroy dry organics. Samples would be cooled as soon as possible after collection.

The residue levels of mercury, lead, cadmium, arsenic, and specific organic compounds are expected to be quite low in water. Therefore, sample size and preservation are extremely important. Samples for elemental analysis will be collected in Teflon or glass bottles. All bottles will be scrupulously washed, acid-washed, and rinsed prior to use. Samples will be immediately acidified to pH 0.5 with nitric acid as per EPA (1974) and Rosain and Wai (1973). All analyses will be based on unfiltered samples.

It is necessary to monitor certain stream parameters to aid in the interpretation of the measured pollutant values. Therefore, additional data to be collected with each biosphere water sample will be flow rate, turbidity, and total non-filterable residue. These data will be used to determine the stream condition at the time of sampling. Contaminant levels are typically related to these factors since the pollutants are often attached to particulate matter.

Also, general stream information will be collected but will not primarily be used to detect changes from year to year or to assess global contamination. The following parameters will be measured at least once during each biosphere sampling cycle: temperature, pH, conductivity, chloride, dissolved oxygen, hardness, biochemical oxygen demand, alkalinity, total organic carbon, phosphorus, fecal coliform, and nitrogenous compounds. The procedures as suggested by Kittrell (1969), EPA (1974), or Standard Methods (1971) will be employed for all analyses.

All samples will be labeled as previously described. The samples will be retained in the custody of the sampler or chief sampler until delivery or shipment to the laboratory. During the presampling, quality assurance will be checked by collection of duplicate samples. Ten duplicate samples will be analyzed along with the regular samples. These analyses should give us a good idea of the extraction and analytical errors inherent in biosphere reserve water sampling.

Air

Air pollutants are divided into two major categories, gases and particulates. The three gaseous pollutants of principal interest in terms of potential biological impact are sulfur dioxide (SO_2), fluorine compounds, and photochemical oxidants (ozone). Of the three, photochemical oxidants resulting from long-term transport from urban areas pose the most likely regional or global impact. An injury threshold of 0.03 ppm of ozone for an exposure of 4 hours has been reported by Heck et al. (1965). Sustained ozone levels in excess of 0.03 ppm are not uncommon in rural, pristine areas of the western United States (Rio Blanco Oil Shale Project, 1976).

Fine particulates are of interest in terms of their trace-element composition. Trace-element "signatures" may serve as indicators of long term transport. Of specific interest are sulfur (sulfate), cadmium, lead, mercury, and arsenic. Beryllium and chromium may also have a potential for long-term transport.

The selection criteria for an air quality monitoring site differ from those for terrestrial or water sampling. It is desirable, as with the other media, to select a location which is not directly impacted by local human activities. At the same time, since air quality monitoring generally requires some form of "air mover" as part of the sampling train, electrical power is a requirement.

An attempt will be made to find locations which meet both these criteria. A ranger observation tower might serve as such a location. If a remote location with power cannot be identified, a deployable long-life power source will be employed. Such a device is the Department of the Navy's Radioisotope Thermoelectric Generator (RTG) (Naval Nuclear-Power Unit, 1975). These units are capable of providing up to 40 watts continuously for up to 5 years. They are available at no cost for demonstration projects providing that the proper safety analysis approvals are obtained. Solar cell systems may be an alternative power source.

Sulfur dioxide will be measured with a continuous monitor based on the principle of ultraviolet absorption or chemiluminescence. Instantaneous measurements would be made at 5- to 15-minute intervals and recorded on a magnetic tape recorder. Such instruments require frequent (weekly) calibration and therefore, require servicing by trained personnel.

Particulates will be monitored with a size-fractionating sequential impactor. A size cut at approximately 2 to 3 micrometers would be used to separate local fugitive dust (>3 micrometers) from fine particulates (<3 micrometers) subject to long-range transport. A sample would be collected over a 24-hour period once every 6 days. Multi-elemental analysis using atomic absorption, x-ray fluorescence, or proton-induced x-ray fluorescence would be utilized for particulate analysis.

For sampling stations with commercial power available, off-the-shelf equipment can be used. For stations utilizing auxiliary power the instrumentation will be re-engineered for low power requirements.

In addition to air monitoring, precipitation will also be collected and analyzed for trace elements and pH.

Atmospheric Deposition

The monitoring of precipitation on sampling sites is an important part of any overall pollutant monitoring system. Sampling sites are located in areas as devoid of local contamination as possible. Therefore, all contaminants must be transported by air. Many pollutants are absorbed on particulate matter which become condensation nuclei for, or are entrained in, rain. Other particles are deposited dry through atmospheric fallout.

The residue levels of pollutants in precipitation often exceed the levels in surface waters and thus are easier to detect. In addition, atmospheric deposition samples should pose relatively few interferences and extraction problems compared to soil and tissues. The monitoring of precipitation has been recommended in the reports "Programme on Man and the Biosphere" (Man and Biosphere, 1974) and "A Global Network for Environmental Monitoring" (Ad Hoc Task Force on GNEM, 1970). A recent report on "Chemical Changes in Atmospheric Deposition and Effects on Agricultural and Forested Lands and Surface Water in the United States" (USDA, 1976) proposed establishment of an atmospheric deposition monitoring network. The system proposes to monitor wet and dry deposition on an event or weekly basis. Initial emphasis will be on nutrient monitoring but will expand to include toxic materials. The proposed monitoring techniques will be employed at the sampling sites with collections and analyses being initially conducted on a monthly basis. Analyses will be made for the toxic materials previously identified. A recording rain gauge and pH meter will be operated at the collection points.

Biological Samples

The monitoring of water poses problems when attempts are made to determine significant changes in the pollutant residue levels. The residue levels in water fluctuate with flow, turbidity, and total non-filterable solids (Delfino and Byrnes, 1975) and the actual residue levels are very low. The sampling of fish for pollutant residues is advantageous since for certain pollutants fish concentrate residues and are integrators of residue levels in the aquatic environment.

Data on residue levels on fish from Yellowstone (EPA, 1972) and remote areas of the Great Smoky Mountains (Huckabee et al. (1974) indicate that reasonable statistical precision can be achieved in fish sampling. Table 3 lists the coefficients of variation for mercury levels in fish and water for these studies. The number of samples required for a given sampling error can be estimated using Figure 1 and the coefficient of variation.

TABLE 3. MERCURY RESIDUES IN FISH AND WATER

LOCATION	TYPE SAMPLE	NUMBER OF SAMPLES	MEAN (ppm)	C.V.
Yellowstone (EPA, 1972)				
Fire Hole R at Madison Junction	Rainbow Trout	23	0.25	0.24
	Water	3	0.0014	0.33
Fire Hole R above Old Faithful	Brown Trout	11	0.14	0.18 (6 composite samples)
	Water	5	0.0025	0.39
Gardner R below Mammoth	Brown Trout	25	0.11	0.45
	Water	5	0.0039	0.70
Gardner R above Mammoth	Brook Trout	18	0.05	0.40 (6 composite samples)
Great Smoky Mountains (Huckabee et al, 1974)	Rainbow Trout 6 Sampling Sites		0.036[1]	0.58[2] (Average, Range: 0.13-1.5)
	Eastern Brook Trout 3 Sampling Sites		0.025[1]	0.24[2] (Average, Range: 0.16-0.40)
	Stone Roller 3 Sampling Sites		0.041[1]	0.48[2] (Average, Range: 0.20-0.82)
	Rosyside Dace	44	0.044	0.30
	Banded Sculpin	27	0.025	0.62

[1] Average residue at sites

[2] Average Coefficient of Variation of sites

The fish sampling would be done downstream from the water-sampling point to avoid disturbance of the sampling site. The choice of species will be determined by several factors including available species, population level, migration patterns, and whether the species is stocked. A large population is required to reduce the impact of sampling. The fish are to be used as an index of watershed contamination so the species selected will have to remain in the stream the year-around and, of course, not be introduced by stocking.

Collections in small streams should be readily accomplished by electrofishing techniques. The number of fish collected in the presampling will depend upon the population. At least 20 young of the year, or 1-year old fish, will be sampled and analyzed. If the population is large enough, composite samples will be collected and analyzed.

Fish will either be wrapped in aluminum foil or placed in clean plastic bags and frozen immediately. The analytical results expressed will be based upon a whole fish basis using standard analytical procedures. Samples will be retained in the custody of the sampler or chief sampler until delivery or shipment to the laboratory.

Vegetation will initially be collected at the same sampling site where soil was collected. The final sampling design may require a separate design but the initial sampling should be adequate to make this determination. The plants to be sampled will be determined somewhat upon availability but it is also intended that an annual and two perennials be collected at each sampling site. Only the most recent year's growth will be collected from perennials and will probably be limited to leaves. Analysis of new growth should permit more rapid determination of changes in residue levels. Each sample will be a composite of 10 approximately equal-sized subsamples collected from different plants of the same species. A duplicate set of samples will be collected at each sampling site. One set of samples will be rinsed with water in the field, while the other samples will remain untouched.

Vegetation will be sealed in Teflon-lined aluminum cans and cooled as soon as possible. Air drying may be required to prevent deterioration if cooling is not possible. All samples will be retained in the custody of the sampler or crew chief until transport or shipment to the laboratory. Contaminants to be determined are the same as for soil. Additional samples will be collected following the soil-sampling pattern as a check on quality control.

Detection of Significant Changes In Global Contamination

The previously described presampling methodology should provide adequate statistical information to design a sampling plan. The number of samples required to achieve the desired sampling error will be estimated. These data, however, will provide sufficient information only to reasonably quantify the residue level at a given point in time or detect a change with time. It is reasonable to expect that these levels vary naturally with time. Since one of the objectives of biosphere monitoring is to detect man-caused changes in residue levels, the magnitude of natural variations must also be assessed. Any changes greater than natural may then be reasonably attributed to man.

To obtain information on natural variations, it will be necessary to sample the sampling site several times, perhaps after various natural phenomena. Factors that may affect residue levels and may even cause significant changes in soil and vegetation residues are the time of sampling relative to the age of the new growth tissue; the amount, intensity, duration, and frequency of rainfall; the time of occurrence of a storm relative to sampling, etc. If the natural variation of residue levels is small relative to man's contamination, the frequency of sampling can be relatively low. If, however, the residue levels vary considerably from week to week or year to year, a larger number of samples will be required.

There are many problems in detecting a significant change in residue levels at a specific site and being able to attribute the change to global contamination. The establishment of numerous sites on a global basis would average out many of the factors contributing to natural variation. If 95 out of 100 biosphere sites reported a significant increase in Pb residues, the probability that man was the causative agent would be very high. Additionally, the establishment of many sites would permit a significant increase in the detection of Pb levels even though the magnitude of the increase was insignificant at the individual sites. Herein lies the value of a global network of integrated monitoring sites.

POLLUTANT IMPACT MONITORING TECHNIQUES

All techniques described above have dealt with assessing pollutant levels in the various environmental components. Although this is valuable and necessary information, it does not give a direct measure of the impact that the pollutant is having on the environmental situation. If reliable impact-measuring techniques are developed and available on a cost-effective basis, they can become of vital importance to the implementation of any biosphere monitoring program and aid significantly in the interpretation of the results. A series of both existing and new environmental impact monitoring devices and techniques will be tested and evaluated. The use of these environmental impact monitoring techniques, coupled with an assessment of pollutant levels in each of the biosphere reserves, will allow quantitative estimates to be made of the long-term impacts of man's activities on the reserve areas. Also, the Biosphere Reserve Monitoring Program should become a technique capable of alerting man to long-term pollutant problems that may be impacting his general health and well-being.

Biomass Measurements

The capability of an area to produce living matter is related to its ecological condition and the stability of the biological communities living in that particular area. Biomass estimates for many years have been used to try to determine potential impacts of pollutants on environmental systems. One problem, up until recently, with biomass estimates has been that most biomass estimates have depended almost exclusively on some variation of a clip and weigh technique.

Now there is an instrument which, once calibrated, can directly read biomass under certain vegetation situations. This instrument is called an electronic capacitance herbage meter. This instrument has been shown to be capable of directly measuring biomass over an area nondestructively. Its theory and operation were described by Neal and Neal (1973). The instrument has limitations, not the least of which is the size of vegetation to be sampled. However, it should be of definite value in certain areas such as upland meadows, tundra areas, or brush-land communities. Once calibrated to a particular vegetation type, it has been shown to be capable of rapidly and cost-effectively making biomass estimates. Because of this ability to make large numbers of observations rapidly, it allows a significant increase to be achieved in the precision of the biomass estimate (Currie et al., 1973; Neal et al., 1976; Morris et al., 1976; and Carpenter et al., 1973).

An herbage meter was borrowed from the U.S. Forest Service in Fresno, California, and was tested on sagebrush in Area 18 of the Nevada Test Site. It was one of the earlier models (Model 18-612). Environmental conditions were difficult with winds up to 30 knots and temperatures around -1° C. The terrain was broken and exposed, and the vegetation was in poor condition. Forty plots were taken on 10 × 4 grid over an area of approximately 70 meters by 140 meters. Vegetation was clipped on each plot, taken to the laboratory, and weighed. The only correction made was the elimination of dead wood; this did not affect the meter reading, but did significantly affect the weight. The correlation coefficient for meter reading versus wet weight was 0.93 with 38 degrees of freedom. The regression equation is expressed in the form:

$$y = \overline{y} + B(X-\overline{x})$$

The appropriate numerical values are:

$$y = 108.12 + 16.82(X-7.95), \text{ or}$$
$$y = -25.6 + 16.82\,X$$

The regression was recalculated using oven-dry weights. The correlation coefficient was 0.89.

A second approach would be to estimate the total biomass for much larger areas. An experimental approach in this area would involve use of multispectral scanning techniques. These techniques were mentioned under the remote sensing portion of this paper.

Long-Term Indicators of Pollutants

It would be desirable for historical purposes and comparison with present-day levels if certain types of measurement could be made on each of the biosphere sites that would be indicative of historical pollutant levels on those sites. Examples would include the possible use of tree rings (Pillay, 1976; Sheppard and Funk, 1975; Lepp, 1975), ice cores (Weiss et al., 1971), and the possible use of bog mud cores. There are some difficulties using some of these approaches. For example, in tree rings, one cannot assume that elements found in a particular growth ring were deposited in the year the growth ring was formed. In most woody trees, water is moved through the xylem over several growth rings and not through the last year of growth. However, in trees where heartwood develops, once the xylem cells have been plugged, little or no water is transported in this area; therefore, one can make the assumption that pollutants trapped in the heartwood area were laid down up to, but not after, the formation of the heartwood. The limit of the heartwood can be determined by counting back on the tree rings.

Another study has also recently been started at EMSL-LV on tree rings in an attempt to understand the mechanisms involved in pollution deposition in tree rings. The purpose is to provide the information mentioned above which will allow us to have confidence that pollutants detected in a particular year of growth were actually laid down in that year. The results of these studies should help in determining the applicability of using tree rings on a sampling site.

The use of ice cores and bog cores is also well known and could be an indicator of long-term pollutant levels. Their use will be explored in the literature, and if feasible, an attempt will be made to implement them in field situations.

Species Diversity Indices

Species diversity indices are being increasingly used as monitoring tools to measure the state of the environment resulting from an insult from a pollutant or group of pollutants. For example, Taylor et al. (1974), under contract to the U.S. Environmental Protection Agency's Corvallis Laboratory, used the following series of indices as background indicators of the condition of the environment around the Colstrip Power Plant. These include:

1. Shannon-Weaver Function
2. Simpson's D
3. Redundancy Index
4. Probability of Interspecific Encounter
5. Probability of Intraspecific Encounter
6. Pie Transformation
7. Fisher's Alpha

Several excellent texts have addressed themselves to the problems associated with sampling in the field for estimating species diversity indices. Some are: An Introduction to Mathematical Ecology (Pielou, 1969); Quantitative Plant Ecology (Greig-Smith, 1964); Ecological Diversity (Pielou, 1975). Some indices that are suitable for possible use on a biosphere sampling site are:

1. Simpson's Measurement of Diversity (Simpson, 1949).

$$L = \frac{\Sigma n\ (n-1)}{N\ (N-1)}$$

L = Simpson's Index

N = Total Number of Individuals

n = Number of Individuals Falling into Various Groups

2. Dice's Measure of Ecological Association (Dice, 1945).

$$(CA) = \frac{hn}{ab}$$

(CA) = Coefficient of Association

h = Number of Samples Containing Species A and B

n = Number of Samples Examined

a = Number of Samples in which Species A Occurs Alone

b = Number of Samples in which Species B Occurs Alone

3. Information Theory Species Diversity Indices (Pielou, 1966a, 1966b).

$$H = \frac{1}{N} \mathrm{Log} \frac{N!}{N_1!N_2!\ldots.N_s!}$$

$$H! = -\Sigma P_i \mathrm{Log}_2 P_i \text{ (Where } P_i = N_i)$$

H = Species Diversity Index

S = Number of Species

N = Total Number of Individuals

N_i = Number of Individuals in the ith Species

NOTE: There are several variations on this equation based on sampling requirements. All appropriate ones will be looked at.

4. Fisher's Alpha (Fisher et al., 1943).

$$S = \alpha^{Ln}\left(1 + \frac{N}{\alpha}\right)$$

S = Number of Species

N = Number of Individuals

α = Fisher's Alpha

In addition to the indices described above, all the data collected will be analyzed to determine the appropriate distribution function. This is vital not only to the estimation of species diversity indices, but the application of more routinely applied statistical techniques. Some of the equations to be considered are given below. The citation given refers to a source where computational solutions have been outlined.

1. Poison Distribution (Archibald, 1948).

$$P(x) = \frac{m^x}{X!} e^{-m}$$

$P(x)$ = Proportion of Observations in the Xth Frequency Class

$P(x)N$ = the Number of Individuals in the Class Xth Frequency Class, given a Total Population of N Individuals

m = Mean Number of Units per Quadrat

x = Integer Value for Frequency Class

2. Neyman Type A (Archibald, 1948).

$$P(x=o) = e^{-m_1(1-e^{-m_2})}$$

$$m_1 = \mu_1/m_2$$

$$m_2 = (\mu_2-\mu_1)/\mu_1$$

Subsequent terms are obtained by substituting $K = 0,1,2,3...$in:

$$P(x=K+1) = \frac{m_1 m_2 e^{-m_2}}{K+1} \sum_{t=0}^{t=K} \frac{m_2^{\,t}}{t!} P(x=K-t)$$

μ_1 = 1st Moment of the Distribution (the mean)

μ_2 = 2nd Moment of the Distribution (the variance)

3. Negative Binomial Distribution (Bliss and Fisher, 1953).

$$P(x) = \frac{(K + X -1)!}{X!(K - 1)!} \frac{R^X}{q^K}$$

$$R = P/q = M/(K + M)$$

Distribution defined by K and M. The parameter M is mean. K is determined as outlined by Bliss and Fisher (1953).

There are other indices that are available for analysis. However, many are dependent on the measurement from randomly selected individuals to their nearest neighbor, or measurement from a randomly selected point to the nearest perennial shrub to that point. Because of ease of sampling in the field, efforts will be restricted to indices that depend on total species counts. The distribution functions described by no means exhaust the possibilities. Other functions will be included as necessary. Among the missing distribution functions, which will be considered, is the normal distribution.

The sampling site size will vary with the type of vegetation. Mature forests will be sampled with sample site size of approximately 0.1 acres. A prism will be used to determine plot boundaries. Sampling in meadows will be done on a sampling site size of 1 square meter. Sample site boundaries will be delineated, using 1 meter square sampling frames. Sampling in shrub communities will use a sample site whose boundaries will be delineated by a collapsible sampling frame 4 meters on a side.

The sampling site system will be essential to the overall experimental design since samples collected for pollutant monitoring for soil and vegetation, at least, will be tied to this overall sample design, although not necessarily sampled within the immediate confines of plot boundaries as described above. Permanent plot locations for pollutant sampling will not be used because changes through time on the same area are desired to be detected, and therefore, a new "random" sample must be drawn for each "time" sample.

Microcosms

Techniques which employ biological indicators for the determination of pollutant impact on a biosphere have been improved in the past few years. Bioindicators have one great advantage over standard analytical pollutant analyses -- they make it possible to determine, many times in a one-step procedure, the direct effect a pollutant has on living organisms. This measurement, after all, is the purpose of all the analytical effort. One indicator technique which is gaining in use is the microcosm concept.

Microcosms have been and are now primarily being used as tools for the evaluation of chemical mobility in soil and to determine whether these toxicants are likely to bioaccumulate or biomagnify. Both of the above uses require that the user know what toxicant has been introduced and what methods are available for both extraction and analysis. This information is then used to predict the fate of these materials. A more relevant use of the microcosm concept has been the effort to identify certain critical system-level parameters which could be sensitive to perturbation. Of the parameters investigated, the two which show the greatest promise are patterns of soil nutrient loss and carbon dioxide evolution (Van Hook et al., 1976). If these parameters can indeed be correlated with system perturbation, then we have a new monitoring tool which would readily indicate system stress even before visible damage was evident.

Available data indicate that there is little doubt that microcosms do respond in a predictable manner to low levels of soil chemical perturbation. However, the effects of environmental stress (water stress, temperature, light, etc.) have not been determined. When it can be shown that such interactions either do not cause effects similar to chemical perturbation or that such effects do not mask chemical perturbation, then its usefulness as a monitoring tool can be established. The lab work will be in a growth chamber where a full range of environmental influences can be evaluated. After environmental stress effects are determined, the effects of both soil-applied and gas-phase pollutants will be studied. The information from these studies is essential for integrating this technique into the biosphere monitoring program.

Bioindicators

The use of biological indicators to determine the effects of pollutants on a given site is a promising technique. Recent studies with a tritium ($^3H_2$) oxidizing microorganism at the EMSL-LV, *Alcaligenes paradoxus*, have shown promise in assessing the available concentrations of certain heavy metals, mercury and lead, in soil. These preliminary studies have shown that, for similar concentrations of these metals in soil and a liquid media, quite different effects on the activity of this microorganism, as determined by its ability to produce tritiated water, are observed. Concentrations as high as 100 ppm of lead (as lead acetate) had no apparent effect on the bacterium in the soil but caused a 50% reduction of activity in the liquid media. For mercury (added as mercuric nitrate) the effect was even more pronounced. In soil a concentration of 100 ppm of mercury resulted in only a 22% reduction in activity as compared to a 37% reduction caused by only 1 ppm in the liquid solution.

The results imply that the impacts of mercury and lead are smaller in soil than in solution and that this organism may prove useful as a determinant of heavy metal availability in soils. Also, the techniques involved in this analysis are quite simple, and fast: results can be obtained within a matter of hours after receipt of a small soil sample. This technique will be developed further at EMSL-LV as a possible rapid screening tool for assessing pollutant impact in biosphere soil systems.

Parameters Monitored and Analytical Support

Many of the early papers written on GEMS or on the biosphere reserve program in general have proposed a variety of pollutants to be monitored on the site. A list of pollutants suggested for monitoring on the biosphere reserves has been given in the MAB Report 20 (Man and Biosphere, 1974), GNEM Report 4, (Ad Hoc Task Force on GNEM, 1970), SCOPE Report 3, (Munn, 1973) and Morgan et al. (1976). Table 4 is an estimate of the types of parameters to be measured in each media of the sampling site for the initial pilot study.

TABLE 4. SUGGESTED LIST OF PARAMETERS TO BE MONITORED AND CONSIDERED FOR BIOSPHERE RESERVE SAMPLING SITES

POLLUTANT	ENVIRONMENTAL COMPONENT				
	Air	Water	Soil	Biota	Rainfall/Dry Deposition
Sulphur Dioxide	X				
Suspended Particulates	X				
Turbidity		X			
Total Nonfilterable Residue		X			
Ozone	X				
DDT*, PCB, Other Chlorinated Hydrocarbons and Organics		X	X	X	X
Cadmium	X	X	X	X	X
Mercury	X	X	X	X	X
Lead	X	X	X	X	X
Arsenic	X	X	X	X	X
Sulphur	X				X
Reactive Hydrocarbons	X				
Stream Flow Rates		X			
Temperature		X			
pH		X	X		X
Conductivity		X			
Total Organic Carbon		X			

* Dichloro Diphenyl Trichloroethane

There is an additional parameter which is referred to as the unknown organic. At this stage, we would recommend a procedure as outlined by Mr. William Donaldson at Athens, Georgia. The general procedure was put forward in a paper entitled "Identification and Measurement of Trace Organics in Water Methodology and Monitoring Systems." This was presented November 17, 1976, at the state-of-the-art seminar supported by the Office of Air, Land, and Water Use, Office of Research and Development, U.S. Environmental Protection Agency. In this paper, Mr. Donaldson proposes that a limited number of samples be completely and totally analyzed and examined for as many forms of organic contaminant as possible. As part of this study, we recommend bringing in a certain number of soil extracts, rain, and water samples to be analyzed by such a technique. The object here would be to determine if there is present in these samples an unexpected environmental contaminant from anthropogenic sources. This is one attempt to try to anticipate potential worldwide pollutants. Table 5 is a list of the types of organic compound that have been identified using this type of an approach for a water sample. Also shown are the amounts detected.

Another approach of a similar nature is in the trace element area. This is to make use of multi-element analytical techniques on a limited number of samples. Two techniques that are applicable are spark-source mass spectrometry and neutron activation analysis. Not all samples will be sent for this multi-element analysis, but composite samples selected to be representative of the entire sampling site will be submitted for multi-element analysis to ensure the detection of any unexpected buildups in various trace elements outside of those elements listed in Table 4.

Scott (Personal Communication, EMSL-LV, 1977) has stated the requirements for trace-element analysis in this type of study:

> "...recommendations are to use very sensitive methods which require a minimum of sample preparation to minimize blank problems. Candidate methods are neutron activation for Hg, As, and Pb with x-ray emission or spark source mass spectrometry for Hg, As, Pb, and Cd. All of these methods can be used for analysis of the solids without dissolution of the samples. If dissolution of the samples can be tolerated, then optical emission or furnace atomic absorption could be used. The detection levels cited for Cd and Pb in water will require the collection of very large quantities so that concentration by a factor of 1,000 will yield levels which are detectable. Gas chromatography or gas chromatography-mass spectrometry can be used for the PCB and DDT although concentration techniques may have to be employed for water.
>
> The sampling phase of this work must be conducted in such a manner that contamination by the sampler does not obscure the true level of the residues. Preservation of the water samples also must be properly accomplished particularly at these low levels. Equally important is the availability of ultra-clean facilities to the analytical laboratory so that sample contamination does not occur."

TABLE 5. VOLATILE ORGANICS IN GROUNDWATER FROM WELL #5 PRIOR TO IN SITU COAL GASIFICATION[1]

Chromatographic Peak No.	Elution Temp. (°C)	Compound	ppb
1	128	toluene	2.0±1
3	145	ethylbenzene	1.5±0.5
4	147	p-xylene	0.5±.25
4A	150	3-heptanone	trace
5	152	styrene	1.0±.5
6	153	o-xylene	0.5±.02
6A	161	isopropylbenzene	0.06±.03
8	168	n-propylbenzene	0.7±.03
8A	169	m-ethyltoluene	0.1±.05
9	170	p-ethyltoluene	0.08±.01
10	172	benzaldehyde	trace
10A	173	1,3,5-trimethylbenzene	0.08±.01
10B	173	$C_{10}H_{20}$ isomer	trace
11	174	cyanobenzene	0.06±.01
11B	175	o-ethyltoluene	0.08±.02
13	178	1,2,4-trimethylbenzene	0.24±.07
13A	179	$C_{10}H_{20}$ isomer	trace
13B	180	n-decane	0.2±.05
13C	181	$C_{10}H_{20}$ isomer	trace
14	183	C_4-alkyl benzene isomer	trace
15	184	C_9H_{10} isomer	trace
16	185	1,2,3-trimethylbenzene	0.3±.04
18	188	$C_{10}H_{20}$ isomer and indane	trace
19	190	indane	trace
19A	190	p-propyltoluene	0.08±.01
20	191	m-propyltoluene	0.04±.03
20A	192	n-butylbenzene	0.04±.03
21	193	$C_{11}H_{24}$ isomer	trace
22	194	o-propyltoluene	trace
22A	195	methylindane isomer	trace
23	196	C_4-alkyl benzene isomer	0.2±.04
24	197	C_4-alkyl benzene isomer	trace
24A	198	methylindane isomer	trace
25	199	n-undecane	0.2±.03
26	200	C_5-alkyl benzene isomer	0.1±.01
26A	201	C_5-alkyl benzene isomer	0.1±.01
27	202	C_4-alkyl benzene isomer	0.2±.01
27A	202	C_5-alkyl benzene isomer	trace
27B	203	$C_{12}H_{26}$ isomer	trace
28	204	tetramethylbenzene isomer	0.3±.02
29	205	C_4-alkyl benzene isomer	0.2±.01
29A	205	methylindan or dimethylstyrene isomer	trace
30	207	C_5-alkyl benzene isomer	trace
31	208	$C_{12}H_{24}$ isomer and C_5-alkyl benzene isomer	trace
32	210	C_5-alkyl benzene isomer	trace
32A	210	$C_{12}H_{24}$ isomer	trace
32B	211	methylindene isomer	0.04±.01
33	211	C_4-alkyl benzene isomer	NQ
33A	212	C_5-alkyl benzene isomer	NQ
33B	212	methylindene isomer	trace
34	213	C_5-alkyl benzene isomer	NQ
34A	213	1,2,3,4-tetramethylnaphthalene	0.06±.03
35	214	methylindene isomer	trace
35A	215	$C_{12}H_{24}$ isomer	trace
35B	215	C_6-alkyl benzene isomer	trace
36	216	dimethylindane isomer	trace
37	217	n-dodecane	0.3±.03
38	218	naphthalene	2.0±.05
39	219	dimethylindane isomer and C_3-alkylindane isomer	trace
40	220	$C_{13}H_{28}$ isomer and C_5-alkyl benzene isomer	trace
41	221	C_6-alkyl benzene isomer	trace
42	222	C_3-alkylindane isomer	trace
43	223	C_6-alkyl benzene isomer	trace
44	224	C_6-alkyl benzene isomer	trace
44A	224	dimethylindane isomer	trace
45	225	C_6-alkyl benzene isomer	0.2±
46	227	$C_{13}H_{26}$ isomer	trace
47	228	$C_{13}H_{28}$ isomer	trace
48	230	C_6-alkyl benzene isomer	0.4±.05
50	231	$C_{14}H_{30}$ isomer	0.1±.03
51	232	dimethylindane isomer	trace
52	233	trimethylindane isomer	trace
52A	234	$C_{13}H_{26}$ isomer	trace
53	235	n-tridecane	0.2±.02
54	237	dimethylindane isomer + trimethylindane isomer	0.1±.05
55	238	[illegible]-methylnaphthalene	200
57	240	C_4-alkyl benzene isomer	trace
58	isothermal	$C_{12}H_{16}$ isomer	
59		$C_{12}H_{16}$ isomer and $C_{13}H_{18}$ isomer	trace
60		C_7-alkyl benzene isomer	trace
61		$C_{13}H_{18}$ isomer	trace
62		$C_{15}H_{32}$ isomer	trace
63		$C_{14}H_{28}$ isomer	trace
64		n-tetradecane	0.2±.01
65		biphenyl	trace
66		ethylnaphthalene isomer	trace

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[1] Pellizzari, D. E. (1977). Quarterly Report No. 4. Identification of Components of Energy-related Waste and Effluents. EPA Contract No. 68-03-2368, Research Triangle Institute, Research Triangle Park, N.C.

QUALITY ASSURANCE

It is expected that a relatively large number of samples would be collected both in the presampling and in the follow-up study phase. It is advantageous to minimize the total number of samples since this is associated with a large portion of the cost of any biosphere reserve monitoring program. Nonetheless, the number of samples is expected to be large. Samples will be submitted for analyses in either the raw form or in the extracted form. The analytical support will follow all quality assurance procedures which are normally included in the EMSL-LV quality assurance protocols. In addition, since the levels of pollutants are expected to be low, the minimum amounts of extraction variability and instrument variability are desirable. Also, because of the nature of some of the elements in question, specialized analytical techniques will have to be employed. Samples will likely be batched and a large number sent for analyses at one time. Check-samples, blank and unmarked samples of known concentrations will be submitted at regular but unscheduled intervals. At least 10% of the total number of samples submitted will be analyzed by an independent laboratory as part of its quality assurance program. All samples will be handled with extreme care to prevent any possible contamination in the lab. This is reflecting again the relatively low concentration levels of pollutants in each of the samples. Reference methods used will be equal to or better than those cited previously. For example, pesticide analyses should follow procedures outlined by Thompson (1974) and Sherma (1976). Complete data sets, including chromatograms from gas chromatographs and where preferable, graphic results of the atomic absorption analyses will be maintained, cataloged, and submitted as part of the data report. An estimate of machine error and an estimate of error due to extraction will be included in the report. Sampling procedures have been covered in detail including sampling-site criteria, number of samples and frequency of sampling in previous sections of this paper. With regard to the preservation of samples, all samples will be kept wherever possible under cold or freezer conditions. All samples stored at Las Vegas will be kept in a refrigerator. It may not be possible, however, to immediately freeze samples in the field because of the remoteness of the sampling stations, but every effort will be made to preserve the samples in as close to the same form as when they were collected. Sample preservation is central to the whole success of a biosphere monitoring program.

Samples will be shipped from the field sites to Las Vegas either in the company of the principal investigators, other members of the field team, or by commercial air freight with arrangements made for immediate pickup upon receipt at the airport. The samples will then be transported immediately to the cold room and stored prior to extraction and/or submission for chemical analyses. Sample identification and coding have been covered in detail previously.

All field data will be recorded in a field notebook similar to the type available from the Nalgene Company, copyright 1973. These are specially designed bound notebooks. It is difficult to remove pages and the books are designed so that they are resistant to chemicals. They are fully immersible in water, may be written on with pencil, ball-point pen, etc., when wet or even when under water.

Field instruments will be maintained and calibrated according to the manufacturers' recommended procedures. Instruments, such as the electronic capacitance herbage meter, will be re-zeroed every 30 minutes throughout the day, as used. The herbage meter will be warmed up for a minimum of 1 hour in the morning prior to use so that it equalizes ambient termperatures. Batteries will be replaced daily.

BIOSPHERE SITE SELECTION AND CHARACTERIZATION - EXAMPLES

Yellowstone National Park

Geographically, Yellowstone National Park lies in the extreme northwest corner of Wyoming with slight extensions into both eastern Idaho and southern portions of Montana. At one time this area was nearly all mountainous. However, at present, approximately one-third of the park is made up of low rolling plateaus formed from lava flows (Christiansen and Blank, 1972). The north, east, and southern portions of the central plateau in the park are extremely mountainous forming parts of the Rocky Mountains (Figure 2).

An aquatic environment is well represented by numerous hot water pools and other geothermal features formed by an enormous reservoir of molten rock beneath the Park. Also, four main rivers drain the Park, one of which drains to the Pacific Ocean--the Snake, and three which drain to the Atlantic Ocean--the Firehole, the Madison, and the Yellowstone rivers. Lakes are abundant with the largest, Yellowstone, and the smaller, Shoshone, Lewis, and Heart Lakes occurring in the Park's southern portion.

Yellowstone National Park consists of approximately 9,100 km^2 and is included on the following U.S. Geological Survey's 15 minute quadrangles: Grassy Lake Reservoir, Canyon Village, Cutoff Mountain, Buffalo Lake, Mammoth, Old Faithful, Gardiner, Sunlight Peak, Crown Butte, Mount Holmes, Madison Junction, Two Ocean Pass, Norris Junction, Tower Junction, Tepee Creek, West Thumb, Eagle Peak, Pelican Cone, Mt. Wallace, and West Yellowstone.

The Park is surrounded by National Forests. The north side is bounded by the Gallatin, the east by the Shoshone, the south by the Bridger-Teton and portions of the west and south by the Targhee.

Ownership

The supervision and jurisdiction of Yellowstone is under the U.S. National Park Service headquartered at Mammoth Hot Springs located at the northern entrance on Highway 89.

The locations and addresses of the U.S. Forest Service District Offices are as follows:

Gallatin - U.S. Federal Building
Box 130
Bozeman, Montana 59715

Shoshone - West Yellowstone Highway
P.O. Box 961
Cody, Wyoming 82414

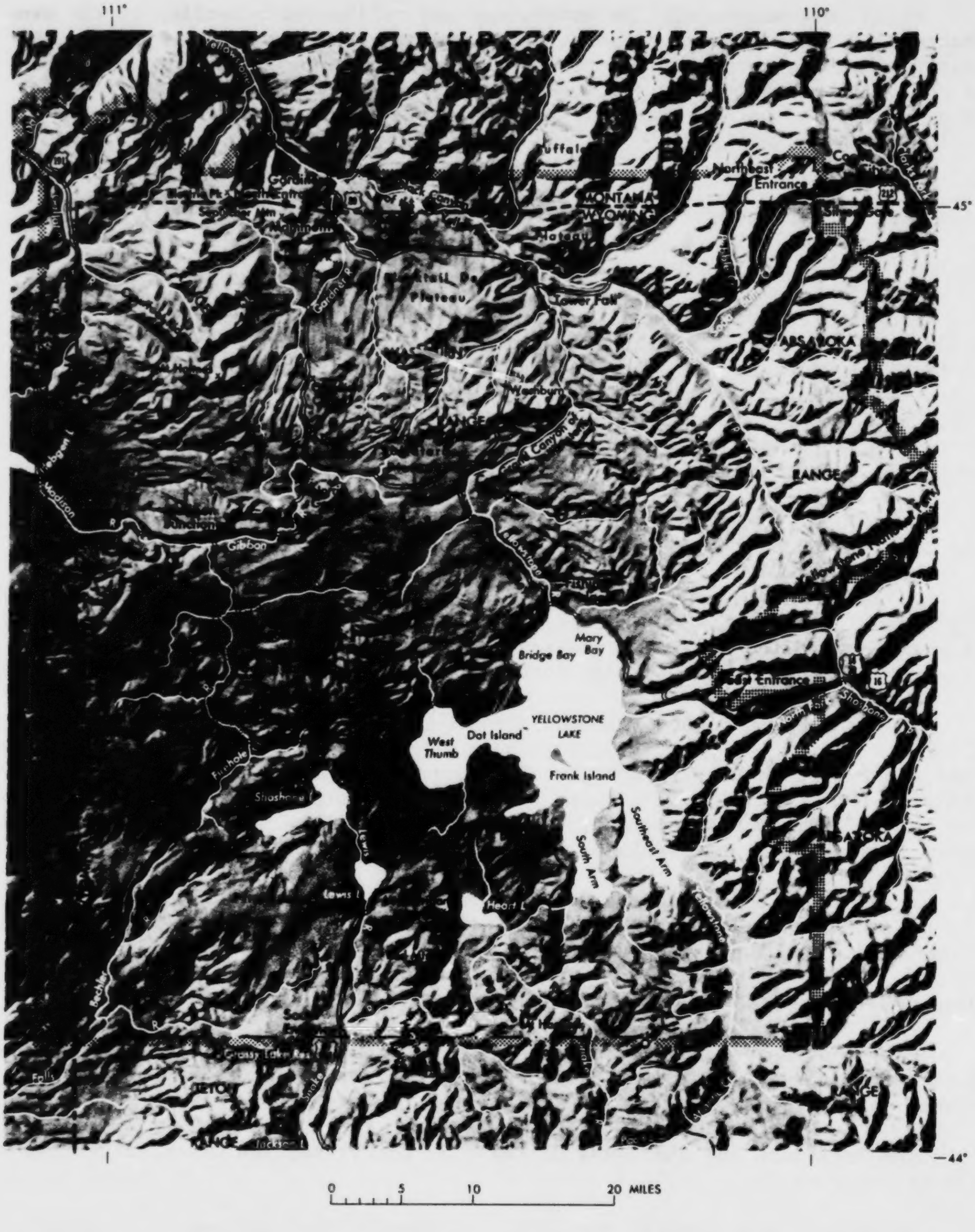

111°
110°
45°
44°
Northeast Entrance
MONTANA
WYOMING
Plateau
Tower Fall
ABSAROKA
Washburn
RANGE
Madison
Gibbon
Hebgen L
Mary Bay
Bridge Bay
YELLOWSTONE LAKE
West Thumb
Dot Island
Frank Island
South Arm
Southeast Arm
East Entrance
Shoshone L
Firehole
Lewis
Lewis L
Heart L
Grassy Lake Res
Snake
Jackson L
RANGE
0
5
10
20 MILES

Figure 2. Map of Yellowstone National Park.

Targhee - 420 N. Bridge Street
Anthony, Idaho 83445

Bridger-Teton - U.S. Forest Service
Jackson, Wyoming 83001

Accessibility (Logistics)

Accessibility into portions of the Park by motor vehicles is made possible through the following five major entrances: Gardiner, Cook City, Cody, Teton National Park, and West Yellowstone. State Highways are 191, 20, 287, 89, 14, 16, and 212. These form a network of easily accessible roads through the central portion of the Park; however, many areas such as in the southeast, southwest, and portions of the northeast are accessible only by foot and pack trails. The absence of roads and trails over a large portion of the Park makes exploration difficult.

The small number of service roads that do exist generally parallel the main State Highways. As such, they would not be useful for gaining access into the many remote regions of the Park.

The walking and pack trails are fairly extensive throughout some of the Park. However, any sustained and heavy sampling would require the use of pack animals and/or the use of aircraft. Sample integrity would be difficult under these conditions.

Site Integrity

It is very likely that sites in the southeast, southwest, and northeast portions of the Park are remote enough to be able to maintain site integrity. The occasional penetration by hikers should have a minimal effect. Further, the fact that this is a national park assures protection for the future.

Vegetation Types

Most of the 9,100 square kilometers of Yellowstone National Park has been described as being vegetatively monotonous (Cooper, 1975), having few terrestrial vegetative types. Within the elevational range of approximately 1,650 meters to a high of over 3,000 meters, four major and two minor terrestrial vegetative types have been identified (Despain, 1973). Also, four different aquatic or water-associated types are described:

Spruce - Fir Type (*Picea - Abies*)--Location -- this type is common, but is well developed only in the northwestern corner of the Park. It occupies the northwest and northeast slopes at elevations between 2,100 meters and 2,400 meters on moderately well-drained benches and alluvial flats. It is the most extensive of the very mesic vegetative types.

Dominant Species -- In many areas, *Picea engelmannii* and *P. glauca* dominate to such an extent that *Abies* is present only as seedlings or sapling-sized accidentals (Cooper, 1975). However, many areas are dominated by *A. lasiocarpa* and/or an equal mix of the two dominates. White bark pine (*Pinus albicaulis*) may also be a major component, even the dominant species at times. The average density of spruce ranges from 133 to 178 trees/hectare and fir 173 to 207 trees/hectare. In areas where white bark pine dominates, its density ranges from 126 to 444 trees/hectare (Despain, 1973).

Douglas - Fir type (*Pseudotsuga Menziesii*)--Location -- this type is generally found at lower elevations, 1,800 meters to higher elevations on the south facing slopes where it occurs in a seral role in the Spruce-Fir type. It also represents local forests of the warmest and driest environments usually receiving less than 51 centimeters of rainfall per year (Despain, 1973).

Dominant Species -- The dominant species are *Pseudotsuga menziesii, Populus tremuloides, Pinus contorta,* and mixes of *Picea engelmannii* and *P. glauca.* This forest is also characterized by an understory of big sagebrush *Artemisia tridentata* and various grasses. It can also be distinguished by its many large, fire-scarred, areas.

Lodgepole - Pine type (*Pinus contorta*)--Location -- one of the largest types in the Park, it is generally found in areas where moisture is more favorable, such as pond margins, drainage ways and north-facing slopes. This type is found between 2,300 meters to 2,560 meters elevation and receives between 50 to 100 centimeters of precipitation per year.

Dominant Species -- The lodgepole pine type is dominated by *Pinus contorta* with little or no *Picea* or *Abies* in the understory. The lodgepoles are slower growing and may reach ages in excess of 300 years. Density is about 325 trees/hectare for trees greater than 10 centimeters in diameter (Despain, 1973). White bark pine may also be present in both overstory and understory. The climax condition in lodgepole is perhaps determined by the combination of relatively low precipitation and the nutritionally poor nature of the soils derived from rhyolite.

Meadow type--Locations -- meadows occur at most elevations throughout the Park. They can be subdivided into two subtypes:

a. The wet meadows in which water, usually to a depth of 5 to 8 centimeters covers most of the area for long periods of time during much of the growing season. The dominant vegetation in this subtype is from the genus *Carex*. Also represented are the grasses *Alopecurus aequalis* and *Hordeum brachyantherum* (Reed, 1952).

b. The second meadow subtype is the dry meadow. The dominant species again are from the *Carex* genus; however, the species are different than found in the wet meadows. A greater abundance of grass is found in this subtype including *Bromus spp, Poa palustris,* and *Agrostis spp.*

Cold Desert type--Location -- this type, relatively small in area, lies near Gardiner, Montana, along the northern boundary of the Park at elevations between 1,670 and 1,830 meters (Despain, 1973).

Dominant Species -- This type similar to the Great Basin cold desert formation is dominated by big sagebrush *A. tridentata, Sarcobatus spp, Eurotia lanata,* and the grass *Bouteloua spp.* It is commonly found in areas receiving less than 38 centimeters annual precipitation and on heavy soils derived from shales.

Alpine Tundra--Location -- there is not much information available concerning this type, however, it is found in Yellowstone in areas above 3,000 meters.

Dominant Species -- Plant species include mosses, Mountain avens, and native dandelions.

Riverside Shrub type--Location -- this type occurs along most of the main river systems throughout the Park. It is characterized by shrubs and small tree species, primarily of the *Salix* genus. Dominant species include *S. farrae, S. lutea, S. drummondiana,* and *S. exigua.*

Rivers -- All of the rivers receive runoff of thermal waters from geysers and hot springs that may influence aquatic plant and animal populations in many portions of these water systems. Chemically the rivers in this region are sodium-bicarbonate-chloride waters. Calcium and magnesium occur in considerably lower concentrations. The water chemistry is directly related to the products of weathering of sodium and potassium aluminosilicates together with silica, which largely comprise the bedrock of this region (Wright and Mills, 1967).

Dominant Species -- this type includes *Chara Vulgaris, Potamogeton filiformis, P. strictifolius, P. natans,* and the aquatic mosses *Hygroamblystegium fluviatile* and *Fissidens grandifrons.*

Thermal Pools and Hot Springs--Locations -- thermal pools and hot springs are most common. They are characterized by hot or warm water with temperatures approaching 90° C or higher. Often source temperatures will exceed runoff or mouth temperatures by 10 times within a few hundred meters.

Dominant Species -- As many thermal plants and animal species are temperature tolerant and also, due to the wide variety of temperatures in the many geothermal pools and hot springs, species abundance and population densities change as a function of thermal sources. The following are the common diatom, algal and bacterial species found in the hot waters throughout the Park (Stocker, 1967): *Schizothrix caluiola, Mougeotia spp., Oscillatoria terebriformis, Synechococcus spp., S. minervae, S. lividis, Paracoenia spp., Borillus stearothermophilus, Thermus aquaticus, Calothrix spp., Mastigocladus spp., Chara Vulgaris, Pinnularia microstrauron, Gomphonema parvulum, Achnanthes grimmi, Navicula cincta, Rhopalodia gibberula, Amphora coffeaeformis,* and *Denticula elegans.*

Geology

The initial geologic investigations of Yellowstone were primarily reconnaissance studies conducted by Hayden (1872). His work was primarily concerned with the geography and with the local hot springs and geysers of this area. During the latter part of the 1800's, more geologic and topographic studies were completed by Hague (1896) and Hague and Iddings (1899). Their work showed the presence of extensive rhyolite formations within the Park; however, no attempt was made to map the other geologic formations within the rhyolite complex.

Allen and Day (1935) conducted a detailed investigation of the hot springs. Similarly, Fenner (1934, 1936) reported on the alteration of the rhyolite by hot spring waters. He also reported (1938, 1944) on the petrology of the Gardiner River Complex.

Further studies by Howard (1937) identified and described the geomorphic history of the Grand Canyon of the Yellowstone. During this same period, work on the volcanic activity in Yellowstone was reported by Dorf (1939). He reported that volcanic outbursts occurred intermittently in Yellowstone beginning during the early Eocene and continuing throughout the Tertiary. Rouse (1937) described these volcanic formations as being from andesite and docite, consisting predominantly of breccias and agglomerates, having the appearance of mud flows. He further identified the accumulation of the andesites, breccias, and associated basalts to thicknesses of up to 2,000 meters in the Absaroka Range along the eastern border of the Park. The breccias were also noted to crop out in the Gallatin Range in the northwest corner of the Park, in the Washburn Range north of Yellowstone Lake, and at a number of localities in the foothills of the Wind River and Teton River along the southern boundary.

The centers of volcanic eruption were disputed during these early explorations. For example, intrusive rocks similar to the breccias in composition were found in the Gallatin Range. Hague (1899) interpreted this source of breccias near Electric Peak as being the core of a large volcano. He also identified Hurricane Mesa in the Absaroka Range as the core of another major volcano. Later, Rouse (1937) disagreed and refuted this by reporting that the breccias were deposited by hundreds of small vents and a few volcanos of moderate sizes scattered throughout this area.

Apparently, the eruption of the breccias was followed by an interval of erosion as the rhyolite which covers nearly two-thirds of the Park was reported by Boyd (1961) to have been deposited upon this eroded breccia surface.

Features of the present-day landscape as reported by Keefer (1972) originated from the Pliocene time. He further reported that during this time the entire region was being uplifted to heights several thousand meters above the present elevations. These forces accounted for the many large steep-sided block mountains bounded by normal faults. While some blocks sank, others rose, sometimes on the order of several thousand meters. For example, the Gallatin Range in the northwest corner of the Park was lifted as a rectangular mountain block along two 32-kilometer long normal faults which border this range on each side.

The rise in elevation and the dissection of this region into many mountainous fault blocks gave rise to increases in the rate of erosion. Once slow streams turned into fast moving rivers that cut deeply into the surface features. Rock debris were stripped and carried off. It is believed that at the end of the Pliocene the Yellowstone region was highly dissected mountains consisting of many table topped and canyon lands. Resemblances of this can be seen in the Absaroka Range running along the east side of the Park. This mountain range and the Washburn Range located in the central part today represent small remnants of the vast pile of Absaroka volcanic rocks that once covered all of the Yellowstone region.

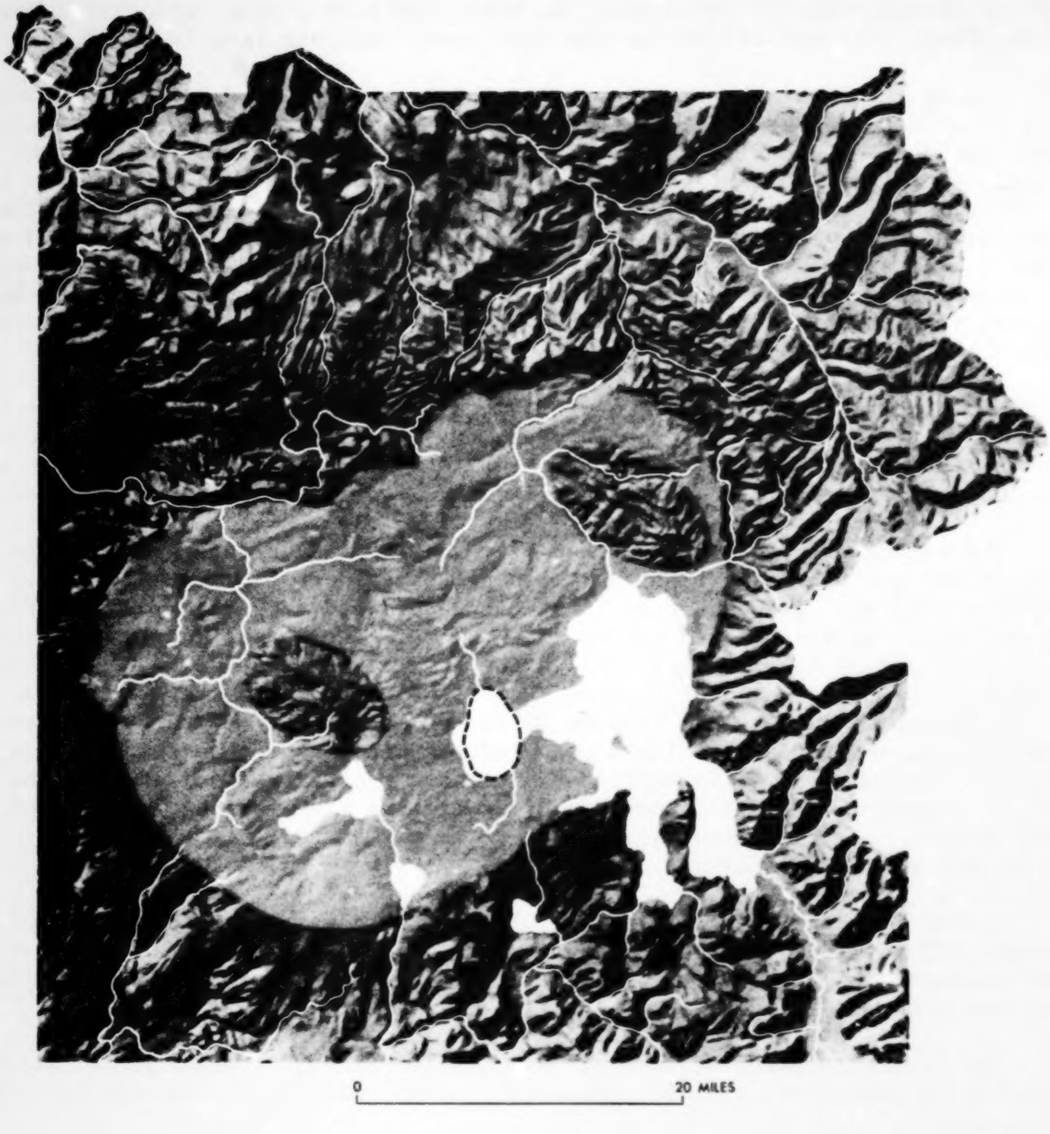


Figure 3. Outline of the Yellowstone caldera.

At the beginning of the Quaternary period, the formation of the 2,600-square-kilometer Yellowstone caldera began (Figure 3). As the magma built up and accumulated beneath Yellowstone, it developed into such an explosive state that two caldera-forming eruptions occurred--the first, 2,000,000 years ago, and the second, 600,000 years ago. As both eruptions affect the central part of the Park, features related to the first eruption were largely destroyed.

During the first eruption lava and ash flows filled old canyons and valleys which had been eroded into the "Absaroka pile." Eventually much of the older landscape was buried by ash. As the hot pumice, ash, and molten rock cooled, it formed horizontal sheets of compact rock similar in composition to rhyolite, also termed ash-flow tuff or Yellowstone tuff (Keefer, 1972). The rhyolite plateau is made up of this ash flow and welded tuff with subsidiary rhyolite domes of basalt and rhyolite-basalt mixed lava. The Yellowstone tuff is exposed over a 1,550 square kilometer area within the Park along with the plateau flow which covers nearly 2,600 square kilometers in the Madison Central and Pitchstone Plateaus (Boyd, 1961).

With the removal of hundreds of cubic kilometers of molten rock after the eruptions, the caldera collapsed into the two major magma chambers. The depth of collapse has been estimated to be several thousand meters. In part the basin occupied by Yellowstone Lake owes its existence to the caldera collapse.

The second eruption was confined primarily to the caldera proper. The lava poured out from many fissures flooding the caldera floor. As the lava began to fill the caldera basin, it overflowed toward the southwestern portion of the Park. Again the lava cooled, forming the gently rolling plateau surface of central Yellowstone commonly called the Rhyolite Plateau as previously described. This plateau covering more than 2,000 square kilometers is characterized by moderate valleys and rolling hills formed between adjacent lava flows, with streams and rivers flowing in many of the ready-made channels. The Rhyolite and the ash-flow tuffs are the predominant rock along many of the Park roads. A number of basalt flows did occur in this area forming some of the most unusual rock formations in the Park. They are characterized by a series of upright many-sided columns.

Another caldera-forming event occurred in the central Yellowstone region between 125,000 and 200,000 years ago. This eruption of rhyolite ash flows and the subsequent collapse of the caldera formed the deep depression now filled by the west thumb of Yellowstone Lake.

The last outpouring of lava occurred 60,000 to 75,000 years ago. The hot water and steam activity still remain as a vivid reminder of Yellowstone's volcanic past.

In 1972, Christiansen and Blank described the major rocks formed after the three volcanic periods. Formed during the first period were rocks comprised of precaldera - Junction Butte basalt and rhyolite, the Huckleberry Ridge tuff of the Yellowstone Group, and the post-caldera Lewis Canyon rhyolite and basalt of the narrows. Most of the rock formed during the second period is largely buried; however, the Mesa Falls tuff, also, of the Yellowstone Group, is present at the surface in certain areas. The rocks of the third volcanic eruption are represented by the precaldera Mount Jackson rhyolite, post-Lava Creek basalt, Lava Creek tuff, and Yellowstone tuff.

The final sculpturing of Yellowstone occurred during the last 100,000 years by glaciation. This region was glaciated at least three times. The glaciations were from oldest to youngest, the pre-Bull Lake, Bull Lake, and Pinedale. Their precise age and duration are imperfectly known, but estimates based on a few radiometric determinations are: (1) the oldest glaciation (pre-Bull Lake glaciation) began more than 300,000 years ago and ended between 180,000 and 200,000 years ago; (2) Bull Lake Glaciation began about 125,000 years ago and ended more than 45,000 years ago; (3) Pinedale Glaciation began about 25,000 years ago and ended about 8,500 years ago (Keefer, 1972). The pre-Bull Lake and Bull Lake are known only from scattered deposits of rock debris, glacial moraines, and other features, but the distribution of these deposits indicates that glaciers were widespread throughout the region and occurred both between and during eruptions of the Rhyolite Plateau. The effects of the Pinedale glaciers, on the other hand, are obvious in many parts of the Park, and the history of this youngest glacial cycle is known in much greater detail than that of the two older ones.

In the early stages of Pinedale Glaciation, an enormous icefield built up in the high Absaroka Range southeast of the Park area. A glacier, fed by this icefield, flowed northward down the upper Yellowstone valley and into the basin now occupied by Yellowstone Lake. At about the same time, another great icefield formed in the mountains north of the Park and sent tongues of ice southward toward the lower Yellowstone and Lamar River valleys. Smaller valley glaciers flowed westward out of the Absaroka Range along the east edge of the Park, and still others formed along the main ridges and valleys of the Gallatin Range, in the northwestern part of the Park. Thus, many huge masses of ice from the north, east, and southeast converged and met in the Park.

For the next 10,000 years, the ice thickened and spread out over more and more of the Park area. The mass, centered over the Yellowstone Lake basin, grew to a depth of 900 meters or more and dominated the entire scene. Eventually, the Pinedale glaciers covered about 90 percent of Yellowstone (Figure 4). Only the west edge of the Park and perhaps a few of the highest peaks and ridges within the Park remained free of ice (Keefer, 1972).

After their maximum advance, the Pinedale glaciers began to melt, leaving behind the rock debris they had gouged from the landscape and had pushed or carried along with them. These glacial moraines are now found in many areas throughout the Park. In places, glacial ice and/or rock debris formed natural dams across stream valleys, thereby impounding lakes. Parts of Hayden Valley, for example, contain layers of very fine sand, silt, and clay several tens of meters thick that accumulated along the bottom of a large lake. This lake formed behind a glacial dam across the Yellowstone River near Upper Falls. Some of the glacial dams broke and released water catastrophically, causing giant floods; the occurrence of one such flood is particularly evident along the Yellowstone River valley near Gardiner, Montana.

Figure 4. Extent of ice in Yellowstone National Park.

By about 12,000 years ago the thick Pinedale ice sheet had melted entirely from the Yellowstone Lake basin and most other areas of the Park, although valley glaciers continued to exist in the mountains until about 8,500 years ago. Then following a short period of total disappearance, small icefields formed again in the heads of some of the higher mountain valleys. Since the melting of the Pinedale ice, however, none has descended as a glacier into the lower stretches of the valleys (Keefer, 1972).

Soils

Soils data from Yellowstone are extremely limited. The only data available from within the Park boundaries are shown on the General Wyoming soil map, Figure 5, as prepared by the U.S. Soil Conservation Service (Wyoming General Soil Survey, 1975).

All of the soil associations within the Park are classified as soils typical of mountains or mountain valleys. They are all of similar origin, formed from either residual or transported materials.

The only detailed soil survey completed is of the Gallatin Canyon Area. This area borders a small portion of the extreme northwest corner of the Park beginning approximately 48 kilometers north of West Yellowstone and ending about 24 kilometers southwest of Bozeman. Six different soil associations that have been identified to be on the Park boundary include the Loberg, Teton-Cheadle, Garlet-Loberg, Leavitt-Hanson, Leavitt-Loberg, and the miscellaneous steep mountainous lands (Olsen et al., 1971).

The extent of these associations within the Park is unknown, however, the soil descriptions of each are as follows.

Loberg Association -- This soil association is on forested, undulating to hilly and mountainous, glacial till uplands. Slopes range from 8 to 40 percent. It occurs in large areas in the basins of West Fork, Beaver, Porcupine, Portal, Squaw, and Moose Creeks as well as other major tributaries of the Gallatin River. It is mostly located midway between the steep bedrock uplands and the grassland soils developed in till of lower elevations or the valley floor. Much of this association has "kettle and kame" topography characteristic of till deposits. However, there are some long, smooth, steep slopes primarily on the upper portions of the association. Rock outcrops occur in some delineations as narrow ridges or knobs. There are some very stony areas that are usually associated with the steeper slopes. Vegetation consists mostly of lodgepole pine and Douglas fir with an understory of pine grass, elk sedge, and shrubs. This association is between 1,800 to 2,400 meters in elevation. Mean annual precipitation is 60 to 120 centimeters; 40 to 100 centimeters of this comes in the form of snow. It is common to have a frost during each of the summer months. This association consists of about 8,000 hectares, or approximately 17 percent of the survey area. Loberg soils comprise about 80 percent of the association. Soils resting on bedrock at depths of less than 50 centimeters, rock outcrop, rock rubble, and other miscellaneous soils make up about 20 percent of the survey area. Logging operations on this association are severely hampered on slopes that exceed 30 percent. Very stony and rock outcrop areas also present some difficulties in the placement and building of

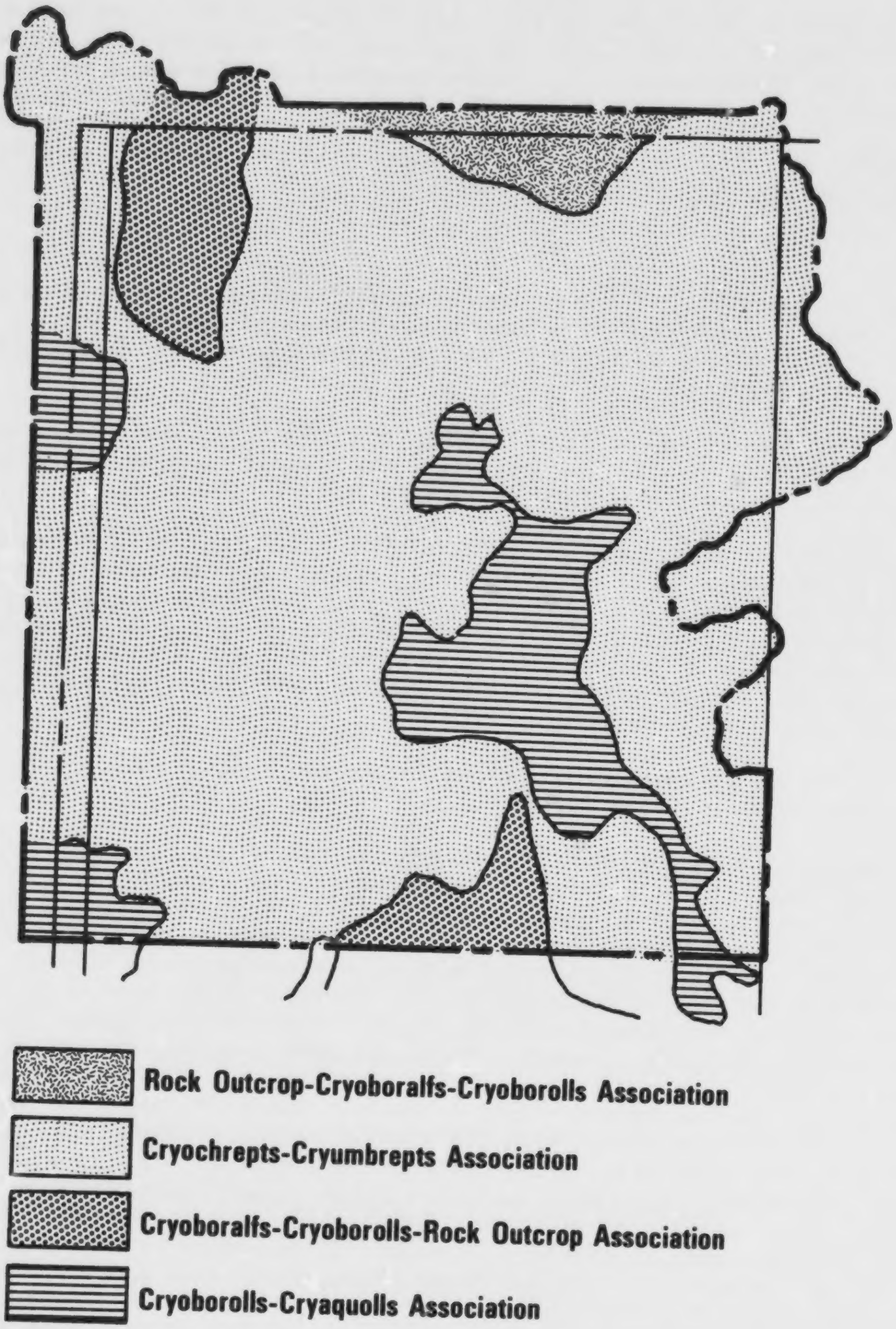

Rock Outcrop-Cryoboralfs-Cryoborolls Association
Cryochrepts-Cryumbrepts Association
Cryoboralfs-Cryoborolls-Rock Outcrop Association
Cryoborolls-Cryaquolls Association

Figure 5. Soil associations in Yellowstone National Park.

logging roads. Soil losses can be held to a minimum by the proper location and grading of these roads.

Loberg soils are drained well. A typical profile under a thin layer of forest litter consists of a light gray or light grayish brown loam over a thick brown clayey subsoil that is gravelly, cobbly and stony. The substratum is a very gravelly to stony clay loam. They are noncalcareous to depths of 1 meter or more. Coarse fragments increase with depth from about 35% in the upper part of the profile to over 60% in the substratum. There are stones on the surface and throughout the profile. These soils are slowly permeable. They are used primarily for timber products. They represent about 80% of the association.

Leavitt-Loberg Association--This soil association is a complex of grassland and forested soils developed in glacial till on undulating to hilly and mountainous uplands. The four main areas of occurrence are between Beaver and the West Fork Creeks, along Porcupine and Tepee Creek drainages, and also south of the mouth of Cinnamon Creek. It occurs at elevations ranging between 1,800 and 2,000 meters. Slopes range from 8% to 40%. Much of this association has a "kettle and kame" topography. Vegetation on the Leavitt soils consists of Idaho fescue, rough fescue, mountain brome, shrubby cinquefoil, bluegrasses, and forbs. Lodgepole pine and Douglas fir are the primary vegetation on the Loberg soils. Annual precipitation ranges from about 50 to 100 centimeters, of which 30 to 60 centimeters come in the form of snow. It is common to have a frost during each of the summer months. There are approximately 2,200 hectares in this association comprising about 4.8 percent of the survey area.

Teton-Cheadle Association--This grassland association of soils is primarily on mountain "park" areas. Landscapes are generally smooth, but may include some ledgerock outcrop areas downslope from the rounded ridges. Dominant slopes are between 10 and 40 percent. This association occurs at elevations between 1,700 and 2,560 meters. Annual precipitation ranges from about 50 centimeters to near 150 centimeters at the higher elevations; 30 to 100 centimeters of this is in the form of snow. Frost usually occurs at least once during each of the summer months at elevations above 1,800 meters. Vegetation consists of Idaho and rough fescues, mountain brome, shrubby cinquefoil, bluegrasses, and forbs. This association comprises about 1,900 hectares, or approximately 4.1 percent of the survey area. Teton soils make up about 65%, Cheadle 20%, and other miscellaneous soils and rock outcrops about 15%. Cheadle soils are on the convex surfaces, along ridges, and rounded knobs. Teton soils are on the long smooth slopes between the ridges and drainageways. Hobacker and Adel soils are most common along creeks. Rock outcrop is usually associated with the Cheadle soils along ridges and points of hills in areas of less than a hectare in size. This association is used for grazing of livestock and wildlife. Elk are the prime users of this association in the Porcupine and Tepee Creek drainages and also in the upper portions of Portal, Beaver, Taylor Fork, and other drainages. Proper range management practices and wildlife control measures will maintain and improve the vigor and amount of the more desirable species of grass.

Teton soils are well drained. A typical profile has 18 to 30 centimeters of very dark brown or black loam surface layer, a grayish brown or yellowish brown, prismatic and blocky structured, light clay loam subsoil, and a calcareous loam substratum that rests on partially weathered sandstone. Depth to bedrock is usually between 75 and 100 centimeters. Gravel and cobble content throughout the profile ranges from 5% to 30%. These are moderately permeable soils with medium to moderately slow runoff. They represent about 65% of the association.

Cheadle soils are excessively drained. A typical profile has a thin, dark grayish brown to very dark grayish brown gravelly loam surface layer, a weak blocky structured, grayish brown, gravelly loam subsoil, and a calcareous gravelly to very gravelly loam substratum. Fractured hard bedrock occurs within 50 centimeters of the surface usually between 25 to 45 centimeters. Runoff is rapid. Cheadle soils represent about 20% of the association.

Garlet-Loberg Association--This soil association is on steep and very steep mountain slopes. Sharp ridges separated by deep cut canyons characterize the landscape. Rock outcrop, rock rubble, and landslide areas are common. This association is at elevations of 1,800 to 2,600 meters. Annual precipitation ranges from 60 to 120 centimeters; 60 to 100 centimeters of this comes in the form of snow. Vegetation consists of lodgepole pine and Douglas fir with an understory of pine grass, elk sedge, and shrubs. This association comprises about 11,000 hectares, or approximately 23.2 percent of the survey area. The major soil in this association is Garlet--very gravelly to stony loam. It comprises about 65 percent; Loberg stony soils, 20 percent; Teton, Cheadle, and other soils 15 percent. Garlet occurs on the long steep mountain slopes between the ridges and the drainageways unless interrupted by the occurrence of Loberg soils on the lower portion of the landscape. These forested soils which developed in till also occur at the head of drainageways, immeditely below steep mountain cirques. This association is primarily used as watershed; however, some logging is done at lower elevations on some of the less sloping areas. Wildlife also graze the "park" areas and grass-shrub areas along drainageways.

Leavitt-Hanson Association--This is a grassland association of soils on undulating to steep glacial till uplands. Landscapes are complex and typically glacial till "kettle and kame" topography. Most of the slopes are between 8 and 35 percent. This association commonly occurs midway between the forested till soil areas and the soils of the valley terraces below. It is at elevations of 1,600 to 2,000 meters. Annual precipitation is 50 to 75 centimeters; 30 to 50 centimeters of this comes in the form of snow. Frost can be expected to occur at least once during each of the summer months above 1,800 meters. Vegetation consists mostly of Idaho and rough fescues, bluegrasses, forbes, big sage and other shrubs. This association comprises about 2,500 hectares, or approximately 5.4 percent of the survey area. The largest areas of this association are located on Porcupine, Tepee, West Fork, and Beaver Creek drainages. Leavitt stony loam is the dominant soil type; however, there are areas of cobbly loam and some areas free of coarse fragments in the surface layer. The latter is most common on the north-facing slopes of the Porcupine Creek drainage. In this area the Leavitt soils have thicker, dark-colored surface layers than is modal for the series. Leavitt soils consistently occupy the sloping lands between the ridges, or knobs, and the drainageways and concave areas. Hanson very cobbly and stony soils are on the knobs and ridges. The highest concentration of cobbles and stones is associated with this soil. Adel, Michelson, or Hobacker soils occur throughout the association. Some seeped soil areas occur along some drainageways. An occasional small intermittent lake is trapped in the undulating uplands. Leavitt soils make up about 60% of the association, Hanson 30%, and other miscellaneous soils 10%. This association is used almost entirely for grazing. Good range management practices are essential to the maintenance and improvement of the native range on this association.

Leavitt soils are drained well. A typical profile is over 1.5 meters deep. It has a dark brown or very dark brown, loam surface layer, 20 to 40 centimeters thick, and a dark grayish brown or brown cobbly subsoil of heavy clay loam to light clay texture. The substratum is gravelly to very gravelly and cobbly clay loam. They are lime-free to depths of 50 to 90 centimeters and become strongly calcareous below. Coarse fragments in the surface layer range from 0 to 30%, increasing to 35 to 60% through the subsoil and substratum. Permeability is moderately slow. Effective rooting depth is more than 90 centimeters.

Hanson soils are drained well. A typical profile is over 1.5 meters deep. It has a 25-centimeter very dark brown or black, noncalcareous, very cobbly loam surface layer; a dark grayish brown, calcareous, very cobbly loam subsurface horizon and a nearly white, strongly calcareous, very cobbly to very stony loam subsoil and substratum. Throughout the association, the Hanson soils have surface layers of loam, gravelly to very gravelly loam, cobbly to very cobbly loam and stony to very stony loam. Very cobbly and stony loam is dominant. Thickness of the dark-colored surface layer varies from 18 to 40 centimeters. Content of coarse fragments throughout the profile varies from 35 to 60%. They usually increase with depth.

Miscellaneous Steep Mountainous Lands--This association consists of miscellaneous lands, rockland, rock outcrops and rock rubble on steep and very steep canyon sidewalls and ridges. The majority of this association is located along the Gallatin River Canyon. Miscellaneous lands consist of soils of variable textures and variable depths over bedrock. The content of rock fragments in these soils varies from those with only a few pebbles in them to those that are very cobbly and stony. Vegetation consists mostly of lodgepole pine and Douglas fir; however, there are grassland areas and some mixed timber and grass areas. Timber growth is quite variable, ranging from a few scattered trees to some dense groves. The thicker stands are on north-facing slopes and along coulees. Logging on this association is prohibited by the very steep slopes except on the lower, less sloping fans and footslopes. Grazing is primarily by wildlife. This association comprises about 10,000 hectares or approximately 21 percent of the survey area. The shallower soils usually occur on convex slopes along ridges. The deeper soils are on fans and footslopes at lower elevations. About 25 percent of the association consists of rock outcrop and rock rubble. They occur at all levels in the landscape; however, rock outcrop is dominant on the upper slopes. Limestone rockland is most common along the Gallatin River Canyon; however, rockland at the head of side drainages at higher elevations consists of older granitic and andesitic rocks. Much of the soil on the steep slopes has formed in material moved down slope by gravitational creep. Soils on the lower slopes are developed mostly in local colluvial and alluvial materials.

Hydrology

The initial points for two of the most extensive drainage systems in the United States are located within Yellowstone National Park on the eastern side, the Missouri river system via the Yellowstone, Madison, and Gallatin Rivers; and on the western side the Columbia River system via the Snake River. These surface waters are fed by an annual precipitation which averages approximately 40 centimeters at Old Faithful and Mammoth, and increasing with increasing elevation in the Park's many mountainous regions.

The elevational gradient of many of the Park's broad and flat-bottomed rivers ranges from 2 to 6 meters per kilometer. However, a number of streams and rivers drop an average of 9 to 19 meters per kilometer (Keefer, 1972).

Although Yellowstone is rich in surface waters, such as its many streams, rivers, and lakes, its most famous attractions are its many thermal features. The number of individual thermal hot springs and pools has been estimated to be from 2,500 to 10,000. They are scattered throughout many regions of the Park on hillsides, in valleys, frequently following rivers or near lakeshores and exposed in the open or concealed in the extensive forests.

Two essential ingredients are necessary for thermal activity, the first being heat. Contrary to popular opinion the underground temperatures have not cooled measurably during the last 100 years. According to Keefer (1972) geologic studies have indicated that very high heat flows have continued for at least the past 40,000 years. The lowest elevation in the Park where boiling springs are found is 1,800 meters in the Yellowstone Canyon, whereas, the site at Washburn Springs, about 2,500 meters, is perhaps as high as that of any springs for which data are available. The difference in the boiling points at these two places is 1.84° C (Allen and Day, 1935). In the more important hot-spring areas the boiling point of water varies around 93° C, fluctuating with the atmospheric pressure at a rate of about 0.01° C for every 0.25 millimeters in the barometer readings.

Dissolved mineral matter in the hot-spring waters ranges from 1 gram to less than 3 grams per liter. The mineral constituents in the alkaline waters consist mainly of silica with chloride, bicarbonate, and sulphate of sodium, and in sulphate waters, silica, sulphuric acid, and sulphates of common rock metals. Apparently, these minerals have an insignificant effect upon the boiling point. In waters containing large amounts of sulphuric acid or ammonium sulphate, the elevation of the boiling temperature may range from 0.05° C to 0.10° C, but springs of such composition are very unusual in the Yellowstone Park (Allen and Day, 1935).

The second ingredient for thermal activity is water. Studies described by Keefer (1972) indicated that nearly all of the water associated with the thermal activities originates above ground as rain and/or snow with little coming from the underlying magma. Research drill holes in Yellowstone have also indicated that surface waters drain into underground passages reaching depths of over 300 meters. As the waters increase in temperature, a corresponding decrease in weight (density) occurs. As a result, the hot water rises toward the surface being pushed upward by colder waters which in turn sink and keep the water channels filled, thus a giant convection current operates continuously supplying very hot water to the thermal pools and springs. Extensive data on temperature ranges and discharge rates of thermal waters in Yellowstone National Park are given by Allen and Day (1935).

Paleobotany

In 1970 Baker reported that the analytical data from pollen and seeds obtained from cores of soil collected near Yellowstone Lake indicated that initial woody plants in this region were *Pinus albicaulis, Picea engelmanii, Abies lasiocarpa, Populus balsamifera,* and *Juniperus communis*.

Baker further concluded that vegetation near the tree line was a subalpine parkland or alpine tundra during the late glacial period. A cold, moist climate is implied by this type of vegetation with an average annual temperature 13.9° C cooler than at present. This estimated 13.9° C temperature change is apparently a good estimate as the closest weather station shows the present average annual temperature to be 1° C. Approximations of mean annual temperatures during late glacial periods is near -3° C.

During the post glacial period, 11,500 ± 350 years ago, as determined by radiocarbon dating of sediments collected by Baker (1970), there was a change in vegetative type. During this period, the *Pinus contorta* zone was dominated by the lodgepole pine. *Pseudotsuga* was present but not abundant, as low pollen percentages were found for this species. The older portion of this post glacial zone was characterized by a *Pinus contorta, Pinus albicaulis* community lacking any *Picea* and *Abies* species. This vegetation suggests a cool but much drier climate than during the later glacial periods. The mid-portion of this zone, 50,000 to 10,160 years old, indicates a greater domination of *P. contorta*. The pollen spectra resembles the present day *P. contorta* forest and suggests that this period had the warmest and driest climate of the post glacial period.

From the past 5,000 years to the present time, this region is characterized by increases in *Picea* and *Abies* and a higher percentage of *Cyperaceae* pollen. All three are represented by macrofossils. The plant community was probably a *Pinus contorta* forest similar to the present. The pollen and macrofossils of *Picea* and *Abies* suggest a climate slightly cooler and moister than that of the mid-portion.

In another pollen-dating study conducted near Yellowstone National Park by Waddington and Wright (1974) similar results as reported by Baker (1970) were obtained. Waddington and Wright concluded that alpine vegetation or a spruce-fir parkland prevailed on the Yellowstone plateau, back to the time of deglaciation more than 14,360 years ago.

About 11,500 years ago the vegetation shifted rapidly to a mosiac of spruce-fir-white bark pine and lodgepole pine, perhaps with some openings of *Artemisia*, implying a warmer climate. The trend culminated in the Altithermal interval, here dated as 9,000 to 45,000 years ago, when lodgepole pine probably dominated the entire Yellowstone plateau. A slight subsequent increase in spruce and fir pollen implies a reversal of the climatic trend.

Meteorology

The Continental Divide which passes through this biosphere reserve site, along with the many mountain ranges that run in a variety of different directions and orientations, make climatic generalizations and pattern recognition extremely difficult.

Meteorology data as reported by Cooper (1975) indicate that the precipitation regime changes from the western Wyoming area, where monthly precipitation is fairly uniform, to the central portions of Wyoming which have wider monthly variations and peak during the month of May. He further states that available data obtained near the northern portions of Yellowstone National Park show generally low precipitation and relatively high temperatures which would coincide with the development of the xeric portion of the *Pseudotsuga* vegetation type.

The highest precipitation for the general area was recorded at Island Park Dam, one of the lowest recording stations (1,920 meters in elevation). This station lies in the Island Park Basin some 10 kilometers east of the Yellowstone plateau. Nearly 53 kilometers due east and 452 meters higher, the Lake Yellowstone station records less precipitation and virtually the same temperature regime as the Island Park Dam station (see Table 6). The higher precipitation at Island Park Dam can be attributed to the approach effect generated as air masses are forced upward after accumulating moisture while traversing the Snake River Plains. It is notable that the dry *Pseudotsuga* series stands that one might expect to find on the low altitude, south-facing slopes of the Centennial Range to the north of Island Park are extremely scarce and poorly developed owing to the high rainfall of this basin.

Approach effects, cold air drainage, valley effects, and other meteorological phenomena peculiar to mountainous regions virtually preclude extrapolation of climatic area much beyond any recording station.

The climate data as shown on Table 6 are from available studies in or near the boundaries of Yellowstone National Park. At best, they represent the climate of the forest community in their immediate vicinity.

Additional records show that the average yearly temperature near Yellowstone Lake ranges from 0° C to 1° C, and is 1.5° C at Old Faithful. Also, snow accumulation ranges from 1.5 to 30 meters throughout much of the Park.

TABLE 6. CLIMATOLOGICAL DATA BY MONTHS FOR STATIONS REPRESENTING BASAL ELEVATIONS IN AND NEAR YELLOWSTONE PARK. (Cooper, 1975)

STATION	ELEVATION Feet (Meters)		WINTER			SUMMER			Mean Annual Values
			Dec.	Jan.	Feb.	June	July	Aug.	
Mammoth, Wyoming	6230	T[a]	22.6	18.5	19.6	54.3	62.9	60.8	37.9
	(1899)	P[b]	1.10	1.08	1.01	2.24	1.15	1.23	15.33
Lamar Ranger Station, Wyoming	6470	T	16.3	12.2	16.9	51.7	58.3	56.3	36.0
	(1972)	P	0.86	0.93	0.72	2.11	1.26	1.29	13.43
Cooke City, Montana	7553	T	-	-	-	-	-	-	33.5
	(2302)	P	-	-	-	-	-	-	27.64
West Yellowstone, Montana	6662	T	15.0	11.7	16.2	51.5	59.6	57.1	35.1
	(2030)	P	2.18	2.50	1.81	2.44	1.26	1.62	21.22
Lake Yellowstone, Wyoming	7762	T	-	-	-	-	-	-	-
	(2366)	P	1.69	1.90	1.53	2.18	1.38	1.38	19.87
Island Park Dam, Idaho	6300	T	19.5	15.6	16.8	52.6	60.5	59.6	36.2
	(1920)	P	2.92	6.16	3.24	3.56	1.01	1.32	32.29

T[a] - Temperatures in °F

P[b] - Precipitation in inches

Sequoia-Kings Canyon National Park

The Sequoia-Kings Canyon National Park biosphere reserve consists of two nearly equal-sized adjoining portions (Figure 6). Geographically, Kings Canyon National Park lies to the north, bordered by the Sierra National Forest on both its west side and northernmost point, and the Inyo National Forest on its east side. The Kings Canyon portion is the smaller of the two, consisting of approximately 1,445 square kilometers and is included on the following U.S. Geological Survey's 15-minute quadrangles: Huntington Lake, Patterson Mountain, Black Cap Mountain, Tehipite Dome, Mt. Goddard, Marion Peak, Big Pine, Mt. Pinchot, Waucoba Mountain, and Independence.

The southern portion, Sequoia National Park, is bounded by Inyo National Forest on its east side and Sequoia National Forest to the south. The west side is predominately bordered by private land with a small portion surrounded by the Sierra National Forest. This portion consists of 1,618 square kilometers and is included on the following U.S. Geological Survey's 15-minute quadrangles: Giant Forest, Kaweah, Triple Divide Peak, Mineral King, Mount Whitney, Kern Peak, Olancha, and Big Pine.

Both of these National Parks are under the supervision of the U.S. National Park Service, headquartered at Three Rivers, California.

Topographically, this area is a mountainous region, ranging from slightly more than 350 meters in elevation on its western boundary to over 4,400 meters in elevation at the summit of Mount Whitney on its eastern side (Vankat, 1970). It lies predominantly on the western slopes of the southern portion of the Sierra Nevada.

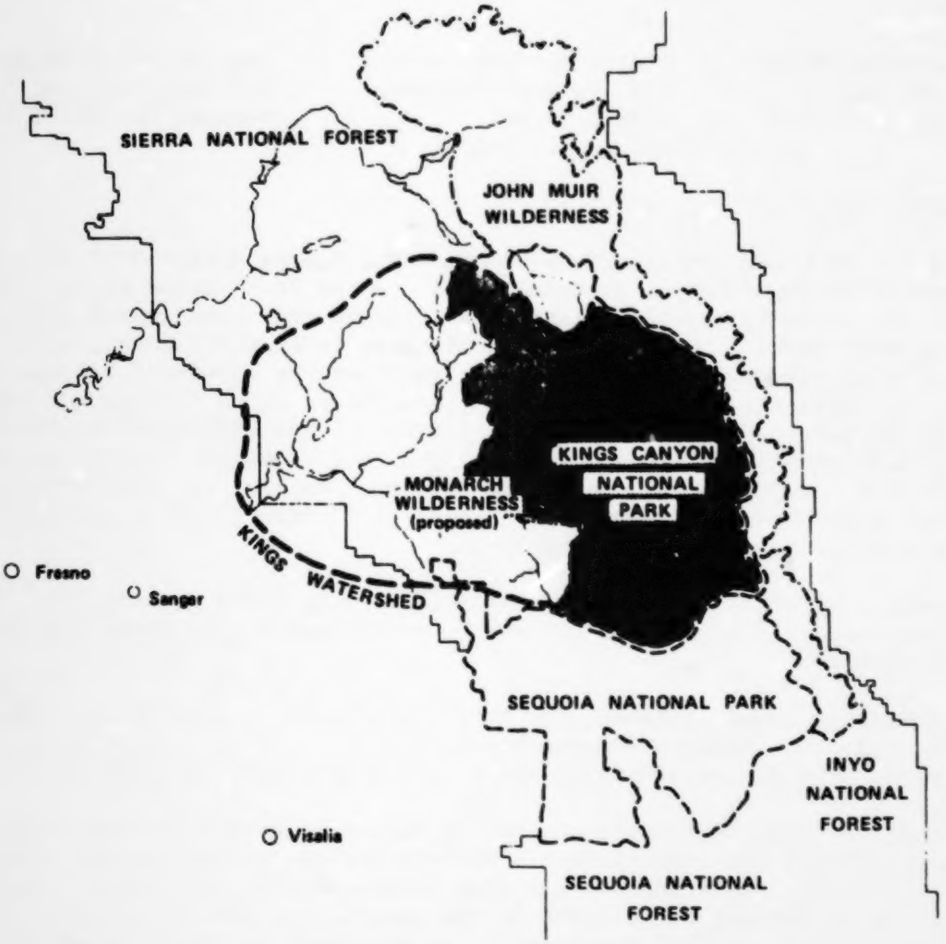
Geologically, it is made up of mesozoic granitic which is typical of the Sierra Nevada batholith. Also, scattered throughout are pre-Cretaceous metamorphic and metasedimentary rock outcroppings. As expected, the soils are typical of the parent material (Matthews and Burnett, 1966).

This region is typical of the climatic patterns of many western mountain ranges: increasing precipitation and decreasing temperature with increasing elevation. Local climatic data have indicated this region to be typically Mediterranean with warm dry summers and cool wet winters (Vankat, 1970). Also, winter precipitation falls as rain in the low elevations and snow, at times quite heavy, in the middle and upper elevations.

Vegetatively this region is composed of both montane and subalpine forests with meadows and lakes scattered throughout both forest types. The dominant plant genera are *Pinus* and *Abies* with a scattering of the distinctive species, *Sequoia gigantea* throughout the montane forests.

Ownership

Kings Canyon and Sequoia are two separate adjoining National Parks. They are under the jurisdiction of the U.S. Park Service's Regional Office located at 450 Golden Gate Avenue in San Francisco, California. The resident headquarters for both parks is located at Three Rivers, California. Also, the


SIERRA NATIONAL FOREST
JOHN MUIR WILDERNESS
KINGS CANYON NATIONAL PARK
MONARCH WILDERNESS (proposed)
KINGS WATERSHED
Fresno
Sanger
Visalia
SEQUOIA NATIONAL PARK
INYO NATIONAL FOREST
SEQUOIA NATIONAL FOREST

NOTE: WILDERNESS AREAS AND NATIONAL PARK AREAS WITHIN THE KINGS RIVER WATERSHED ARE SHADED

EXHIBIT
1

CONSULTIVE PLANNERS

Figure 6. Kings River watershed.

jurisdiction of these two parks is under the direction of a single resident superintendent.

The locations and addresses of the district offices of the U.S. Forest Service whose forests border the Kings Canyon and Sequoia National Parks are as follows:

Sequoia National Forest
900 W. Grand Avenue
Porterville, CA 93257

Sierra National Forest
U.S. Federal Building
1130 O Street
Fresno, CA 93721

Inyo National Forest
2957 Birch Street
Bishop, CA 93514

Accessibility

There are no motor vehicle roads crossing the Sierra Nevada mountains in either Sequoia or Kings Canyon National Parks. A number of paved and/or light duty roads do, however, provide access into parts of the southern and western portions of both Parks. The most notable of these include California State Highway 198 entering at Ash Mountain in the southwestern corner of Sequoia and extending approximately 29 kilometers north near Grant Grove Village. A number of U.S. Forest Service light duty and recreational roads exit near the Village on Highway 198 running east toward Kings Canyon, but end about 3.2 kilometers west of the Park boundary. Another light duty road enters near Oak Grove continuing east exiting near Silver City. Access is limited on this road during the winter months, as it is not maintained.

The only road entering Kings Canyon is California State Highway 180. This road, approximately 11 kilometers in length, enters near Cedar Grove and ends at Zumwalt Meadows.

The remaining areas of these two parks are accessible only by foot and pack trails. As this area is covered by a network of trails too numerous to identify here, only the major trails and access points will be identified.

The Pacific Crest Trail runs the entire length of both Parks paralleling the eastern boundary and accessible via Whitney Portal, Kearsarge Pass, and Bishop Pass. Other trails include the High Sierra and the California hiking and riding trails running north-south in the central portion of Sequoia. A number of trails running both north-south and east-west in Kings Canyon are apparently not named. Extensive sampling in this area would require the use of pack animals and/or the use of aircraft. Sample integrity would be difficult under many conditions.

Site Integrity

As part of the National Park System, the Parks are reserved, in theory, forever. Therefore every confidence can be had that the ownership of the land is not likely to change. Also, the Parks are big enough that adequate buffer zones can be established around each of the actual sampling sites. If the sites are properly chosen, human interference on these sites should be at a minimum. Also, very little management activity occurs, such as forest cutting, etc., and therefore there is little likelihood that the site will be impacted from this type of activity.

Vegetation types

The vegetation in this area has been identified and mapped by Vankat (1970) and the Natural Resources Management Corporation (1975).

Twelve major vegetative types and subtypes have been identified in this region. These types, along with other pertinent information, are listed as follows:

Deciduous Oak Woodland Vegetative Type--Location -- primarily in the western portion of the Parks at elevations between 400 meters and 1,500 meters.

Aspect -- consists of scattered trees, few shrubs and a dense herbaceous understory. This type is broken into two subtypes, the Blue Oak and the California Black Oak.

Blue Oak Subtype--Location -- occurs primarily in the lower and middle elevations between 400 meters and 800 meters. Dominant vegetation -- *Quercus douglasii, Q. wislizeni* and *Aesculus californica* are the common tree species with *Arctostaphylos viscida* and *Rhamnus crocea* common. The vegetative cover commonly exceeds 80% with shrubs contributing less than 2%, trees between 30 and 80%, and herbaceous species contributing up to 80% at times.

California Black Oak Subtype--Location -- occurs primarily in the middle and upper elevations between 800 meters and 1,500 meters. Dominant vegetation -- *Q. kelloggii, Q. douglasii, Aesculus californica, Umbellularia californica,* and *Q. wislizeni* are the dominant tree species along with dominant shrub species, *Cercis occidentalis* and *Rhamnus crocea.* Total vegetative cover is generally over 80% with shrubs contributing 3% and tree species from 65% to 90%.

Grassland Vegetative Type--Location -- closely associated with the deciduous oak woodland type at elevations from 400 meters to 1,500 meters. Dominant vegetation -- perennial bunchgrasses. Many areas, however, have been taken over by annuals, many of which are not common to California. Vegetative cover can approach 100%, because of the successful invasion of annuals. In many areas, 94% of the total cover can consist of these species.

Chaparral Vegetation Type--Location -- this type occurs throughout the western portion of the Park usually between 400 meters and 1,600 meters in elevation. This type is dominated by shrubs which form dense canopies. It is divided into two subtypes, the Chamise and the mixed.

1. Chamise Chaparral Subtype--Location -- occurs on the west and southern exposures of many drainages throughout the Park. It also occurs at the lower and middle elevational ranges, 400 meters to 900 meters. Dominant species -- *Adenostoma fasciculatum* is the most dominant species along with *Ceanothus cuneatus* and *Arctostaphylos viscida.* Ground cover is usually 85% and 95% with *Adenostoma fasciculatum* accounting for 75% of this total. Trees are commonly absent but may be scattered near type boundaries (ecotonal areas). Herbaceous species can contribute 30% to 50% of the ground cover, especially during the spring months when adequate moisture is available.

2. Mixed Chaparral Subtype--Location -- commonly occurs on the north and east slopes at the middle and higher elevations, 900 meters to 1,600 meters. Dominant vegetation -- closely related to the oak woodland subtypes with *Aesculus californica* and *Q. wislizeni* being the dominant tree species with *Quercus chrysolepis* common. Common shrubs include *Rhus diversiloba, Lonicera interrupta* and *Cercis occidentalis*. Ground cover can exceed 94% with herbaceous species contributing from 50% to 75%, shrubs 30% to 60% and trees 40% to 60%.

Yucca Vegetation Type--Location -- Foothill portions usually within the elevational ranges of 600 to 1,500 meters. Found on very steep slopes of metamorphic or metasedimentary rock. Dominant species -- *Yucca whipplei*.

Live Oak Woodland Vegetation Type--Location -- occurs generally within 400 meters to 2,300 meters in elevation. However, in some areas such as in Kern Canyon it is found up to 2,600 meters in elevation. This vegetation type has been broken into two subtypes, the lowland and the upland.

1. Lowland Live Oak Woodland Subtype--Location -- found primarily in the low elevations, 400 meters to 1,100 meters, in riparian habitats. Dominant species -- *Aesculus californica* and *Q. wislizeni* are the dominant tree species, with *Q. douglasii* and *Umbellularia californica* common. Common shrub species include *Rhus trilobata, Ceanothus velutinus* and *Fremontia californica* with *Rhus diversiloba* and *Cercis occidentalis* being dominant. Vegetative cover averages around 90%, with herbaceous species contributing between 20% and 80%, shrubs between 15% and 35%, and tree species between 30% and 80%.

2. Upland Live Oak Woodland Subtype--Location -- normally found on steep rocky slopes at the upper elevations, 1,100 meters to 2,300 meters. Dominant species -- *Q. wislizeni* and *Umbellularia californica*. The vegetative cover is commonly around 75% and is composed almost entirely of the two dominant species *Q. wislizeni* and *U. californica*.

Montane Chaparral Vegetation Type--Location -- this type is found throughout the Park at elevations ranging from 1,200 to 3,300 meters. Dominant species -- It is dominated by a dense cover of shrubs such as *Arctostaphylos patula, A. manzanita, Ceanothus cordulatus, Prunus emarginata,* and many species of *Salix*. Apparently this vegetation type has not been extensively studied, as it is thought that due to the species diversity, many subvegetative types could be made.

Coniferous Forest Vegetation Type--Location -- this type, similar to the Montane Chaparral vegetation type, occurs throughout the Parks. It occurs primarily between 1,400 meters to 3,500 meters in elevation and is subdivided into the following six subtypes.

1. Yellow Pine Coniferous Forest Subtype--Location -- it is found over a wide elevational range, 1,400 meters to 2,700 meters, and under a variety of exposures. A division within this subtype can be made between *Pinus ponderosa* and *Pinus jeffreyi*. Dominant species -- The Ponderosa pine community is dominated by *P. ponderosa, Libocedrus decurrens, Q. kelloggii, P. lambertiana,* and *Abies concolor*. Also found are *Q. chrysolepis, Chamaebatia foliolosa,* and *Arctostaphylos viscida*. The total vegetative cover exceeds 80% at times with her-

baceous species contributing between 0.1% and 10%. Shrub cover is extremely variable, depending on the area. Tree cover varies between a low of 60% and a high of 95%. The Jeffrey pine communities are also commonly found throughout the Parks, usually on south and west facing slopes. The dominant tree species include *P. jeffreyi*, *Libocedrus decurrens*, and *Abies concolor*. *Arctostaphylos patula* is the dominant shrub. Total vegetative cover is generally less than found in the *P. ponderosa* communities, being around 65%. Herbaceous species contribute around 20% with tree and shrubs contributing between 40% and 60%.

2. White Fir Coniferous Forest Subtype--Location -- this type is found over a wide elevational range, 1,500 meters to 2,600 meters, and is quite variable in species composition. At the lower elevations it contains elements of the yellow pine subtype, and elements of the red fir and lodgepole pine subtypes at the upper elevations. Dominant species -- Perhaps the most notable distinction in this subtype is between groves which contain *Sequoiadendron giganteum* and those without. The area containing *S. giganteum* also includes a mixture of conifers such as *Abies concolor*, *Libocedrus decurrens*, *Pinus lambertiana*, *P. ponderosa*, and the black oak *Quercus kelloggii*. At higher elevations *P. jeffreyi* replaces *P. ponderosa*, and decreases of *Q. kelloggii* and *L. decurrens* are evident. Those areas which lack *S. giganteum* are dominated by the tree species *A. concolor*, *P. lambertiana*, *L. decurrens*, and *Q. kelloggii*. The dominant shrub is *Rosa spithamea*. In many areas, however, shrubs are altogether absent. Vegetative cover varies between 75% and 95%, with annual species contributing between 1% and 25%, shrubs 0% to 25%, and trees generally over 75%.

3. Red Fir Coniferous Forest Subtype--Location -- this subtype is generally found in the 2,100-meter to 3,200-meter elevational range. It contains elements of the white fir subtype at lower elevations and at the higher elevations may contain elements of the lodgepole pine subtype. Dominant species -- The major species are the red fir, *Abies magnifica*, along with the pine, *Pinus contorta*. *A. concolor* is also an important species in many areas of this subtype. Shrubs are noticeably absent in this subtype. Vegetative cover is quite variable, usually varying between 40% and 95% depending on area and exposure. Herbaceous species usually contribute between 1% and 5% with the remaining being supplied by the tree species.

4. Lodgepole Pine Coniferous Forest Subtype--Location -- the lodgepole pine subtype is commonly found in all areas of the Park between 2,100 meters and 3,300 meters in elevation. Dominant species -- *Pinus contorta* is the dominant species, occurring in pure stands throughout many areas. Only one shrub, *Ribes montigenum*, is considered significant in this subtype. Vegetative cover is near 80% with annual species contributing 30%, shrubs 0% to 15%, and trees up to a high of 80%.

5. Foxtail, Western White, and White Bark Pine Coniferous Forest Subtype--Location -- this subtype is a subalpine community found throughout the Parks between 2,900 and 3,600 meters in elevation. Dominant species -- Most of the timberline stands are composed of *P. balfouriana*, *P. monticola*, and *P. albicaulis*. In some areas *P. contorta* can be considered a member of this subtype. Shrub species in this subtype are noticeably absent in many areas. Vegetative cover is normally around 25% but may reach 80% in some areas. Herbaceous species contribute around 10% with the tree species contributing the remainder.

However, depending on location, shrubs may provide up to 10% ground cover.

Juniper Woodland Vegetation Type--Location -- occurs primarily in areas between 900 meters and 1,800 meters elevation throughout the Parks. Dominant species -- This type is similar in aspect to the cold desert formations in Utah and Nevada. It consists of scattered trees, primarily *Juniperus occidentalis* and *Pinus monophylla* in stands of *Artemisia tridentata* and *Cercocarpus ledifolius*. *P. jeffreyi* and *P. ponderosa* can be found intermittently throughout this vegetative type. Vegetative ground cover would be approximately 30% and 40%, with shrub species comprising 75% of the ground cover.

Wet Meadow Vegetation Type--Location -- this type is common throughout the Parks above 1,800 meters in elevation. It is characterized by perennial sedges, bushes and grasses that are normally dependent on abundant moisture throughout the growing season (Bennett, 1965). This type is divided into two subtypes, the coarse-leaved sedges and the fine-leaved sedges.

1. Coarse-Leaved Sedge Wet Meadow Subtype--Location -- common throughout the Parks above 1,800 meters. Dominant species -- Three species of the genus *Carex* are found in this subtype. They include *C. lanuginosa, C. rostrata*, and *C. nebrascensis*. Vegetative cover varies between 90% and 100% depending on season. All three species are of equal importance.

2. Fine-Leaved Sedge Wet Meadow Vegetation Subtype--Location -- common throughout the Parks above 1,800 meters. Dominant species -- This subtype is composed of *Carex festivella, C. vicaria, C. spectabilis, C. subnigricans,* and *Poa pratensis* (Bennett, 1965). Vegetative cover is similar to the coarse-leaved subtype and would be between 90% and 100% depending on available moisture and season.

Woodland Meadow Vegetation Type--Location -- this type also occurs throughout the Park at elevations above 1,000 meters. Dominant species -- This community consists of scattered trees of *Pinus contorta, Populus fremontii, P. trichocarpa*, and *P. tremuloides*. In 1965, Bennett reported that this type probably represents past wet meadows that have been invaded by the cottonwood trees. As such, a herbaceous understory is an important constituent of this vegetative type.

Shorthair Meadow Vegetation Type--Location -- this type is scattered throughout the Park at high elevations, usually above 2,400 meters. Dominant species -- Dense mats of *Carex exserta, Calamagrostis breweri* and *Trisetum spp.* are commonly found in this dry upland meadow type. Ground cover usually exceeds 90% with all three species contributing.

Alpine Fell-Field Vegetation Type--Location -- this type is found throughout the Parks above the timberline. Dominant species -- This vegetative type is a variety of perennial herbs scattered between a rocky terrain. Species commonly found in this type include *Carex helleri, Eriogonum ovalifolium, Ivesia shockleyi* and *Hulsea algida*. Vegetative cover varies depending on exposure, but probably averages near 25%.

Geology

The topography of Kings Canyon-Sequoia National Parks is mountainous, ranging in elevation from 350 meters on the western boundary to 4,418 meters at the summit of Mount Whitney. The major drainage systems include the Kaweah and the Kings Rivers located on the western side, which drain to the San Joaquin Valley. The Kern River drainage of the eastern and southern portions is dominated by canyons, plateaus, and mountain peaks sculptured by glaciers (Vankat, 1970). Lying to the east of the Sierra Nevada escarpment is the Owens Valley.

The geological makeup of the Parks is mostly mesozoic granitic rock typical of the Sierra Nevada batholith with scattered pre-Cretaceous metamorphic and metasedimentary rock outcroppings. In 1958, Ross geologically identified and described an area of about 390 square kilometers in Sequoia and Kings Canyon National Parks. It lies on the western slopes of the Sierra Nevada Mountains in Talane County.

About 78 square kilometers of this area is underlain by metamorphic rocks. The three largest masses, completely surrounded by igneous rocks, are roof pendants. They have a general orientation that parallels the attitude of known roof rocks to the north and west.

Regular, persistent layers of differing mineralogical composition in the schistose rocks of the largest metamorphic body, as well as the interlayering of the schists with marble and quartzite, suggest that metamorphic layering is a reflection of sedimentary bedding. Schistosity is essentially parallel to the metamorphic layering.

The metamorphic body of Redwood Mountain is identified as being metasedimentary rocks similar to the larger mass to the south. The most easterly pendant body probably contains a large amount of silicic metavolcanic rocks and is notably lacking in quartzite and marble. The remaining small metamorphic bodies are either root portions of roof pendants or large zenoliths.

Schist is the most common of the metasedimentary rocks and is most abundant in the western part of the largest metamorphic mass, the Redwood Mountain body, and in some of the large zenoliths. The rocks are dark gray to black on fresh surfaces, but have a distinctive reddish-brown weathered surface. The reddish-brown color is commonly reflected in the soil adjacent to schist outcrops.

An approximate average composition of the schists is 25% potash feldspar and intermediate plagioclase, 25% biotite, and 35% quartz. The remaining 15% is muscovite, epidote in the more calcareous schists, magnetite, zircon, apatite, garnet, and rarely andalusite. The parent rocks were probably shales, argillaceous siltstones, and fine-grained sandstones in an intermixed sequence. An alternation of micaceous-feld-spathic and quartzose layers is common with the layers ranging in thickness from a fraction of a millimeter up to 5 mm. Finegrained, massive quartzite, ranging from cloudy white to dark gray in color, is second to the schist in abundance and is most common in the southeastern portion of the largest pendant. Resistant quartzite beds form prominent narrow ridges on both sides of the Middle Fork of the Kaweah River near

Hospital Rock; the local name Devil's Rockpile is applied to an area of blocky quartzite rubble from the ridge just north of the Hospital Rock Camp. The most common type of quartzite is predominantly quartz with subordinate amounts of feldspar and mica. Small amounts of diopside are also present, as are the common accessory minerals apatite, magnetite, and zircon. The parent rock of the quartzite was sandstone or chert with some argillaceous and calcareous impurities.

Calcareous rocks--in particular, marble--are abundant in a band trending northwest through the largest pendant. The most prominent outcrops of the band are in the canyon of the Marble Fork of the Kaweah River, along Paradise Ridge, and near Crystal Cave. Smaller isolated marble and calchornfels masses are found along General's Highway east of the Ash Mountain Park Headquarters. The fine- to coarse-grained marble is snow white to dark gray in color, much of it is banded, and the alternating gray and white layers probably reflect original bedding. A great variety of calc-silicate minerals has been developed where impurities were present in the marble, or where material has been added from the plutonic rocks. The calc-silicate materials are commonly pod-like and discontinuous, but in some localities well-layered plagioclase-pyroxene hornfels probably reflect original composition and bedding. The calc-silicate minerals are best developed in the isolated calcareous bodies east of the Ash Mountain Park Headquarters and around the Barrington tungsten mine on the North Fork of the Kaweah River. The most common minerals are calcite, pyroxene of the diopside-hedenbergite series, garnet of the grossularite-andradite series, wollastonite, idocrase, quartz, plagioclase, epidote, hornblende, and biotite. Scheelite is also found locally in the calcareous rocks.

Amphibolite and amphibole schist are locally abundant north of Amphitheater Point, and less common as lenses in the schist and quartzite elsewhere in the roof pendants. The amphibolitic rocks are dark green, fine to medium grained, and generally somewhat schistose. Hornblende and intermediate plagioclase are the principal constituents, but some specimens are as much as 40 percent diopside. Biotite, quartz, and clinozoisite are less abundant; magnetite, titanite, apatite, zircon, pyrite, and rutile are present as accessory minerals.

Rocks with relict volcanic or tuffaceous texture are rare in the roof pendants. Some of the hornfels and schist of the easternmost large roof pendant have affinities with volcanic rocks and will be considered as possible metavolcanic rock.

North of Amphitheater Point a small amount of metadacite is present. The rock has a blastoporphyritic texture, with plagioclase, quartz, and hornblende phenocrysts. The square cross-section of the quartz phenocrysts is suggestive of a volcanic origin. Associated specimens with clastic quartz grains suggest a tuff or tuffaceous sediment.

Near the Park Headquarters at Ash Mountain, the Ash Mountain complex was described. The major rock type of this complex is a dark-gray, fine-grained rock of quartz diorite composition which is intruded by a fine-grained, lighter gray rock also of quartz diorite composition. Smaller amounts of quartz diorite, resembling material of the Giant Forest pluton, and granite of the Cactus Point pluton are also present within the complex.

The dark-gray, fine-grained rock contains approximately 60% intermediate andesite and traces of potash feldspar. Quartz composes 15% of the average specimen as does brown biotite. The remaining 10% of the rock is green hornblende. Some hornblende crystals are sieve-like and have a structure resembling schiller structure. Apatite, sphene, zircon, and magnetite are also present. The average grain size of the specimens is 0.2 mm and the crystals are anhedral.

The lighter gray fine-grained rock contains approximately 50% intermediate andesite, 30% anhedral quartz, and 20% yellow- to deep-brown pleochroic, irregular biotite. Allenite is present in some of the specimens, as well as small amounts of apatite, magnetite, and zircon. The average grain size is 0.3 mm and most of the constituents are anhedral.

East of the Park Headquarters hornfelsic fine-grained rocks grade into schistose rocks. The hornfelsic schists resemble the fine-grained rocks of the Ash Mountain complex.

Plutonic rocks underlie the remaining 340 square kilometers. The mineral composition of these rocks is summarized in Table 7. Details on each of these compositions are available from Ross (1958).

Work on the absolute age of granitic rocks based on the lead-alpha activity ratio of the accessory minerals particularly zircon, by Larsen et al., 1952 and 1954, has given an average age of 100 million years (mid-Cretaceous) for several granitic rocks from the Sierra Nevada. Five of these specimens were from the Bishop district, about 64 kilometers northeast of the Sequoia area. Determinations of radioactive argon show that the granitic rocks of the Yosemite Valley area are about 83 to 95 million years old (Evernden et al., 1957).

The granitic province from the Klamath Mountains to Baja, California, contains intrusions as old as the Upper Jurassic and as young as the Upper Cretaceous. The granitic rocks of the Sequoia area belong somewhere within this range; recent work suggests a Cretaceous age.

Matthes (1965) reported that in the Pleistocene Epoch, both the Kaweah Basin and the upper Kern Basin were occupied by glacier systems. These were the most southerly of the major glacier systems of the Cascades-Sierra Nevada chain. Being less favorably situated than those to the north, they were of smaller volume; nevertheless, glaciers of considerable size formed in both basins, especially the Kern, during each of the three glacial stages--the Glacier Point Stage, the El Portal Stage, and the Wisconsin Stage.

In the Kaweah Basin, the development of glaciers was limited by the fact that this basin heads not along the lofty main crest of the Sierra Nevada but on the Great Western Divide and on other secondary crests that are only part way up the Sierra west slope. Evidence is present in this basin for the earliest stage, the Glacier Point, but is extremely meager for the next stage, El Portal. For the most recent stage, the Wisconsin, the records are far better. They indicate that during both of these stages the converging canyons of the

TABLE 7. SUMMARY OF MINERAL COMPOSITIONS OF THE PLUTONIC ROCKS. (Ross, 1958)

ROCK	PLAGIOCLASE		Potash feldspar	Quartz	Biotite	Hornblende	Others	No. of thin sections studied
	An	Percent						
Alaskite	10	20-30	40-50	30	0-tr.		Muscovite 0-tr.	3
Lodgepole granite	15-25	15-45	25-45	25-35	5	0-tr.		7
Pear Lake quartz monzonite	20-25	40	30	30	tr.		Muscovite tr.	1
Cactus Point granite	10-25	10-20	40-70	15-30	3-5	0-tr.	Muscovite 0-tr.	4
Big Baldy granite	20-30	5-60	15-55	20-35	3-5	tr.-2		5
Weaver Lake quartz monzonite	10-35	25-45	25-40	25-35	1-5	0-tr.		11
Big Meadow pluton	30-42	30-75	2-35	15-30	4-7	0-tr.		20
Giant Forest pluton	18-48	30-75	tr.-40	10-35	4-4	0-10	Pyroxene 0-tr.	70
Tokopah porphyritic granodiorite	30-40	45	22	23	5	5		1
Clover Creek granodiorite	20-45	40-55	15-30	20-25	4-7	4-7		3
Cow Creek granodiorite	30-40	50-65	10-15	15-30	5	tr.		2
Potwisha quartz diorite	30-55	55-70	0-tr.	15	7-10	8-20		2
Elk Creek gabbro	45-80	50-85		0-5	0-5	tr.-48	Pyroxene 0-20 Olivine tr.	7

Sphene, magnetite, zircon, apatite and allanite are common accessory minerals; monazite, garnet, and pyrite only locally present.

Kaweah Basin became pathways for cascading ice streams. Even the larger of these streams, however, attained a length of only 16 kilometers. The ice streams, therefore, fell short of uniting to form a major trunk glacier corresponding to the ones in the main drainage basins to the north and in the Kern Basin to the east. They formed relatively small separate glacier systems, one or more in the headwater areas of each of the main branches of the Kaweah. For the most part, the glaciers were confined to the canyons, and these they filled only in part. The lowest altitude reached by the ice in El Portal Stage was about 1,400 meters; in the Wisconsin Stage, about 1,600 meters.

The Kern glacier system was a many-branched ice body fed from ranks of cirques along the high bordering ranges. Since the Kern Canyon extends in a nearly straight line through the middle of the upper Kern Basin, and the tributary canyons branch from it like the ribs in an oak leaf, the Kern glacier system had much the same leaflike pattern.

The maximum extent reached by the Kern glacier system in the Glacier Point Stage cannot be determined with certainty, but the evidence would seem to warrant the inference that the glacier advanced approximately as far as its successor of the El Portal Stage.

Records of El Portal Stage, though incomplete, can be interpreted with more assurance. The volume of ice was then greater in some places than the canyons could hold; the ice locally spread across intervening divides and over benchlands on either side of the main canyon to a total breadth of 6 to 10 kilometers, thus producing a central ice sheet about 78 square kilometers in extent. The overall length of the Kern glacier system was 51 kilometers; the terminus of the trunk glacier lay at an altitude of 1,700 meters in the bend of the canyon to the north of Hockett Peak (at latitude 36°14', which may represent the southern limit reached by glacial ice in the Sierra Nevada).

Records of the Wisconsin Stage are for the most part very well preserved. They indicate that during this stage the Kern glacier system had less volume than during the El Portal Stage and remained a sprawling ice body whose trunk and branches lay confined within their respective canyons as distinct ice streams separated one another by mountain spurs or low divides. The tributary glaciers were as much as 24 kilometers long. The overall length of the Kern glacier system is 40 kilometers. The farthest point reached by the terminus of the trunk glacier coincides with the south boundary of the Park; the boundary posts stand at an altitude of 1,935 meters on the curving outer moraine that marks the extreme limits of the Wisconsin glaciation.

Soils

The soils of the Kings Canyon and Sequoia National Parks have not yet been surveyed. However, surveys of a few areas adjacent to the western boundaries in Fresno and Tulare counties are complete.

Soils that are apparently typical of portions of the Parks consists of (1) excessively drained to well-drained soils of the lower foothills and (2) somewhat excessively drained and well-drained soils of the upper foothills. The soils in this area formed mainly from granitic, metamorphic, serpentine, and basic igneous rocks. Small areas formed on colluvium, and many small valleys formed on local alluvium (Soil Conservation Service, 1971).

The foothills extend to the east from the edge of the San Joaquin Valley. Relief ranges from undulating to very steep, and elevation increases to the east. Except where canyons have been cut, the soils formed in material from granitic rock tend to have smoother, less steep slopes than the other soils. The areas derived from metamorphic, serpentine, or basic igneous rocks generally have rougher, steeper slopes.

The uplands of the Sierra Nevada foothills are not divided physiographically, but are divided on the basis of climate into the lower and upper Sierra Nevada foothills. The gradual increase in average annual precipitation and a decrease in average annual temperature is closely related to the increase in elevation. The lower foothill area is warmer and drier than the upper foothill area.

The following soil series are common in these adjacent areas:

Aiken Series

The Aiken series consists of deep or very deep, well-drained soils that have a fine-textured subsoil. These soils formed in material weathered from basalt. In a typical profile, the surface layer is brown and dark-brown loam about 23 centimeters thick. The subsoil to a depth of several meters is reddish-brown and has a subangular blocky structure. The upper part is clay loam, but the main part of the subsoil is heavy clay. Weathered basalt underlies the soil at depths in excess of 1 meter. The entire profile is slightly acid to medium acid.

Basic igneous rock land is made up of areas that are 50% to 90% outcrops of basalt or metamorphic volcanic rock, mainly hornblende schist. In some areas more than 90% of the surface is basaltic rock. These are the columnar jointed cliffs adjacent to the remnants of old volcanic flows on top of Table Mountain and Squaw Leap.

Most areas of basic igneous rock land are steep to extremely steep, but some areas on hilltops or mesas have more gentle relief. The surface of these areas is generally very rough and broken and is stony as well as rocky. The outcrops are dull or dark in color and irregular in shape.

In most places the soil material between the outcrops is loamy and similar to adjacent soils that were formed from the same rock. Commonly, the depth of soil material is extremely variable within short distances. The natural vegetation is mainly annual grasses and forbs with some shrubs and hardwood trees, including interior live oak and canyon live oak. On north slopes and at higher elevations in the foothills, the cover of woody vegetation increases.

Except for some areas on rock faces, the general drainage is good to somewhat excessive. Runoff is variable; it is rapid in some local areas. However, over most of the areas of this land, surface water can drain into the many vertical cracks in the rocks or be trapped and absorbed by the soil material between the outcrops, where it is released more slowly.

Holland Series

The Holland series consists of deep to very deep, well-drained soils with thick fine-textured subsoils formed in place, under forest, from the weathering of granitic rock, principally quartz diorite and tranodiorite. These soils are inextensive in this survey area; they are in the lower lying parts of more extensive areas of Holland soil that exist in the Sequoia National Forest east of the survey area.

A typical profile in this survey area has a brown, slightly acid, coarse, sandy loam surface layer that is high in organic matter and is about 25 centimeters thick. The boundary between the surface layer and subsoil is not abrupt. The subsoil is a thick, reddish-brown, moderately acid sandy clay loam. It grades into well-weathered granitic rock at a depth of about 2 meters.

Sierra Series

The Sierra series consists of well-drained to somewhat excessively drained soils with a sandy clay loam to clay loam subsoil that formed in place from deep weathering of granitic rock. The parent rock is principally quartz diorite and has a fairly high proportion of dark-colored, iron-bearing minerals. These soils are mostly rolling to very steep and mountainous. Slopes are 3% to 70%. Large outcrops of parent rock are common.

In a typical profile, the surface layer is neutral to slightly acid, grayish-brown sandy loam and is about 33 centimeters in thickness. The subsoil is medium acid, reddish-brown clay loam and brown sandy clay loam about 150 centimeters thick. It is underlain by deeply weathered quartz diorite at a depth of about 2 meters.

Hydrology

The hydrology of the Kings Canyon-Sequoia reserve is limited to the surface description of the Kings River Watershed as described by Kings River Conservation District (Kings River Weather Modification Program, 1975). The described area includes most of the Kings Canyon National Park as shown on Figure 6.

In the Sierra Nevada the annual distribution of stream runoff resembles the uneven distribution of precipitation during the year, except that the greatest amounts of runoff occur during the snowmelt period of April through July. The total annual runoff of the Kings River for the 79 years (1895-96 through 1973-74) of record is shown on Table 8. The average annual runoff during this period is 1,668,500 acre-feet, with the lowest annual recorded during the 1923-24 water year (392,000 acre-feet or 23% of normal) and the highest recorded during the 1968-69 water year (4,386,200 acre-feet or 263% of normal). Approximately 20% of the annual runoff is produced by the North Fork, 40% by the Middle Fork, and the remaining 40% by the Main Fork of the Kings River.

Wide variation in precipitation, snowpack accumulation, and runoff from season to season in the Kings River Watershed is typical of other southern Sierra Nevada watersheds. Table 9 lists the water-year runoff and/or snowmelt season runoff for the Kings River at Piedra, the water-year precipitation for

TABLE 8. KINGS RIVER INVESTIGATION
ANNUAL DISCHARGE OF KINGS RIVER AT PIEDRA

(From Kings River Weather Modification Program, 1975).

Water Year	Runoff 1000 A.F.*	Runoff % Normal	Water Year	Runoff 1000 A.F.	Runoff % Normal
1895-96	1535.7	92.0	1935-36	1876.5	112.5
1896-97	1948.5	116.8	1936-37	2341.0	140.3
1897-98	880.7	52.8	1937-38	3283.3	196.8
1898-99	1278.2	76.7	1938-39	974.2	58.4
1899-00	1306.8	78.3	1939-40	1791.2	107.4
1900-01	2956.0	177.2	1940-41	2543.0	152.4
1901-02	1504.6	90.2	1941-42	1999.4	119.8
1902-03	1639.8	98.3	1942-43	2026.6	121.5
1903-04	1687.2	101.1	1943-44	1168.3	70.0
1904-05	1448.1	86.8	1944-45	2062.5	123.6
1905-06	3900.1	233.7	1945-46	1612.1	96.6
1906-07	2733.2	163.8	1946-47	1107.4	66.4
1907-08	997.0	59.7	1947-48	995.4	59.7
1908-09	2798.6	167.7	1948-49	960.7	57.6
1909-10	1779.0	106.6	1949-50	1280.9	76.8
1910-11	2826.7	169.4	1950-51	1600.8	95.9
1911-12	968.1	58.0	1951-52	2856.0	171.2
1912-13	941.6	56.4	1952-53	1154.7	69.2
1913-14	2548.4	152.7	1953-54	1324.6	79.4
1914-15	1817.1	108.9	1954-55	1122.9	67.3
1915-16	3041.8	182.3	1955-56	2585.5	155.0
1916-17	1892.6	113.4	1956-57	1245.2	74.6
1917-18	1363.7	81.7	1957-58	2544.2	152.5
1918-19	1203.3	72.1	1958-59	806.7	48.3
1919-20	1404.7	84.2	1959-60	714.5	42.8
1920-21	1532.0	91.8	1960-61	569.0	34.0
1921-22	2197.6	131.7	1961-62	1900.2	113.9
1922-23	1555.9	93.3	1962-63	1939.0	116.2
1923-24	392.0	23.5	1963-64	911.5	54.6
1924-25	1290.2	77.3	1964-65	2013.7	120.7
1925-26	1036.7	62.1	1965-66	1215.8	72.9
1926-27	1984.3	118.9	1966-67	3374.3	202.2
1927-28	970.9	58.2	1967-68	843.2	50.5
1928-29	850.0	50.9	1968-69	4386.2	262.9
1929-30	862.7	51.7	1969-70	1330.6	79.7
1930-31	465.4	27.9	1970-71	1174.9	70.4
1931-32	2083.5	124.9	1971-72	859.5	51.5
1932-33	1181.4	70.8	1972-73	2135.4	128.0
1933-34	657.4	39.4	1973-74	2095.9	125.6
1934-35	1621.2	97.5			
			79-Year Average	1668.5	100.0

* See Appendix A for Metric Conversion

the period 1931 through 1970 at Balch Power House and the April 1 snowpack accumulation (expressed as water content in inches) at Rowell Meadows. Variation in these hydrologic parameters from season to season indicates a range of basin conditions which far overshadows the increase in runoff and associated hydrologic parameters through weather modification.

The gauging station at Piedra has been in operation since 1895 and provides the longest set of flows available in the Kings River Basin. The North Fork gauge near Cliff Camp, in operation since 1921, is the second longest set of recorded flows. Other stream gauging stations went into operation in the early 1920's. During the late 1950's and early 1960's, additional gates were installed, principally at damsites and at tributaries of the Kings River. Table 10 shows the number, location, and drainage area of the selected stream gauging stations and Figure 7 presents the length of record available in bar-graph form.

Shown on Figure 8 is a graph illustrating the flows of the Kings River (at Piedra), by water years, in millions of acre-feet. The graph also shows the cumulative deviations from the mean flows, from which the magnitude and duration of historically wet and dry periods can be observed. The three water years from 1958-59 through 1960-61 represent the most severe 3-year drought in the history of recorded flow on Kings River. These three years provided only 43% of the long-term average supply; this can be compared with the 4-year drought from 1927-28 through 1930-31, which had a supply of 48% of average.

Surface water in the Kings River Basin is of excellent mineral quality and suitable for all beneficial uses assigned to it by the California Regional Water Quality Control Board, Central Valley Region (CVWOCB). For management purposes, the CVWQCB has divided the Kings River into five segments--Kings River above Kirch Flat, Kirch Flat to Pine Flat Dam, Pine Flat Dam to Friant-Kern Siphon, Friant-Kern Siphon to People's Weir, and People's Weir to Stinson Weir (North Fork), and from Stinson Weir to Empire Weir No. 2 (South Fork).

Waters of the upper reaches of the Kings River are clear, free from foam or detectable color and odor, a neutral pH, dissolved oxygen near saturation, low levels of dissolved minerals and nutrients, and an aquatic flora and fauna typical of unpolluted waters (Kings River Weather Modification Program, 1975).

Measurement of pH and hardness show the upper Kings River to be neutral, and soft to moderate calcium bicarbonate in nature. Dissolved oxygen levels are high, ranging from 74% to 111% saturation; water temperatures are low, ranging from about 5° C to 18° C with maximums occurring in August or September and minimums in December or January. Concentrations of dissolved minerals are low and no chemical anomalies are apparent.

Concentrations of suspended sediments are low, seldom exceeding 30 mg/1. Figure 8 also indicates that sediment production from the watershed is very low (approximately 1 to 1/2 acre-foot per year) under present conditions. Because of the steep gradients of the streams, little sediment deposition occurs within the project area.

TABLE 9. KINGS RIVER INVESTIGATION
VARIABILITY IN OBSERVED HYDROLOGIC DATA BY SEASON

(From Kings River Weather Modification Program, 1975)

Water Year	Water-Year Runoff % of Avg.	Water-Year Runoff 1000 A.F.	April-July Runoff 1000 A.F.	Water-Year Precip. Balch P.H. Inches*	April 1 Snow-Pack Water Content-Inches Rowell Mdw.
1931	28	465.8	355.2	17.37	
32	133	1083.5	1585.0	33.64	38.3
33	75	1180.9	984.0	21.13	25.1
34	42	658.8	407.2	16.44	14.4
1935	103	1621.3	1335.4	34.30	13.2
36	120	1876.5	1428.8	32.30	31.7
37	149	2340.8	1730.2	38.04	43.1
38	209	3275.1	2316.1	46.12	48.0
39	52	974.4	656.4	22.63	14.8
1940	114	1790.4	1305.5	31.72	32.4
41	162	2542.8	1910.3	38.65	42.7
42	128	2005.3	1553.2	32.05	34.7
43	129	2026.6	1380.7	34.89	38.2
44	74	1168.2	926.9	24.43	25.8
1945	131	2062.4	1517.5	32.39	32.9
46	103	1612.0	1128.1	24.89	20.9
47	71	1107.3	726.4	26.17	18.9
48	63	996.2	868.7	23.84	18.9
49	61	960.7	821.1	21.28	23.2
1950	82	1281.0	1028.3	24.20	22.6
51	102	1601.0	853.7	33.45	11.1
52	182	2856.0	2196.0	39.68	
53	74	1155.0	865.6	21.32	20.6
54	85	1330.0	1060.5	27.08	31.0
1955	73	1143.0	862.0	22.95	19.2
56	172	2695.0	1570.3	41.37	27.0
57	80	1259.0	996.5	25.11	20.1
58	167	2615.0	2016.8	43.77	
59	53	823.7	528.2	17.65	15.4
1960	46	718.9	547.2	18.79	14.8
61	36	571.5	402.4	18.64	12.1
62	119	1871.9	1485.2	33.83	41.7
63	121	1902.0	1409.9	32.33	17.5
64	56	877.9	630.1	21.69	12.5
1965	128	2013.7	1326.2	34.69	25.3
66	77	1215.8	910.8	20.73	19.3
67	215	3374.3	2330.0	49.17	43.1
68	54	843.2	565.7	17.48	16.5
69	280	4386.2	3140.5	60.58	73.9
1970	85	1330.6	886.4		19.3

* See Metric Conversion Table, Appendix A.

Paleobotany

Little information could be gathered on the paleobotany of the Sequoia-Kings Canyon areas.

Meteorology

The climatological patterns found within the Kings Canyon-Sequoia region are profoundly influenced by topography. Total precipitation increases within the Sierra Nevada foothills as the moist air ascends the relatively steep Sierra slope. Precipitation ultimately drops off above 2,700 meters. Grant Grove, at 2,000 meters in elevation, averages approximately 100 centimeters of precipitation annually (Biswell et al., 1966). Thunderstorms are recorded about five days per year at lower elevations, while 8 to 10 recordings per year are typical for higher altitudes.

Amounts of snowfall at low elevations are very light--about 2.5 centimeters annually at elevations of 400 meters--increasing to about 600 centimeters annually above 2,400 meters. At the higher elevation, snow remains throughout the winter. Accumulations of 180 to 200 centimeters are not uncommon, and depths of 300 centimeters or more have been recorded. Typically, it is around the 10th of May before the last snow melts at Grant Grove.

In general, average temperature decreases as altitude increases with a wide range of temperatures represented within the Park region. In July, daily maximum temperatures average over 38° C within the thermal belt associated with the Sierra Nevada foothills, which extends for a distance up river canyons. Higher in the mountains, summer temperatures are cooler than the valley, and winter temperatures may be quite cold. Stations from 1,700 meters to 2,100 meters have averages in July below 18° C and in January from -1° C to 0° C. Table 11 shows the precipitation and temperatures at Ash Mountain elevation 500 meters and Giant Forest at 1,953 meters during 1964 (Vankat, 1970).

In open areas of the region the prevailing wind direction is from the northwest during most of the year, although south-easterly winds are more common during November, December, and January. In mountainous terrain there is a tendency for air to move up-slope during the day and to drain down-slope during the night. Relative humidity is fairly high during the winter months, ranging from 50% to 70%. Low readings are the rule during the rest of the year. Late summer and fall are particularly dry in this area (Kings River Weather Modification Program, 1975).

TABLE 10. KINGS RIVER BASIN GAUGING STATIONS

(From Kings River Weather Modification Program, 1975)

Station No.	Name and Location	Drainage Area (sq. mi.)*
2220	Kings River at Piedra	1687
2217	Mill Creek near Piedra	127
2215	Kings River below Pine Flat Drum	1545
2185	Kings River below North Fork	1342
2135	Kings River above North Fork	952
2130	Kings River near Hume	835
2184	North Fork Kings River below Dinkey Creek	387
2165	North Fork Kings River above Dinkey Creek	250
2150	North Fork Kings River near Cliff Camp	181
2146	Helms Creek below Courtright Dam	39.7
2145	Helms Creek at Sand Meadows	34.7
2180	Dinkey Creek at Mouth	136
2170	Dinkey Creek at Dinkey Meadow	50.8

* See Metric Conversion Table, Appendix A.

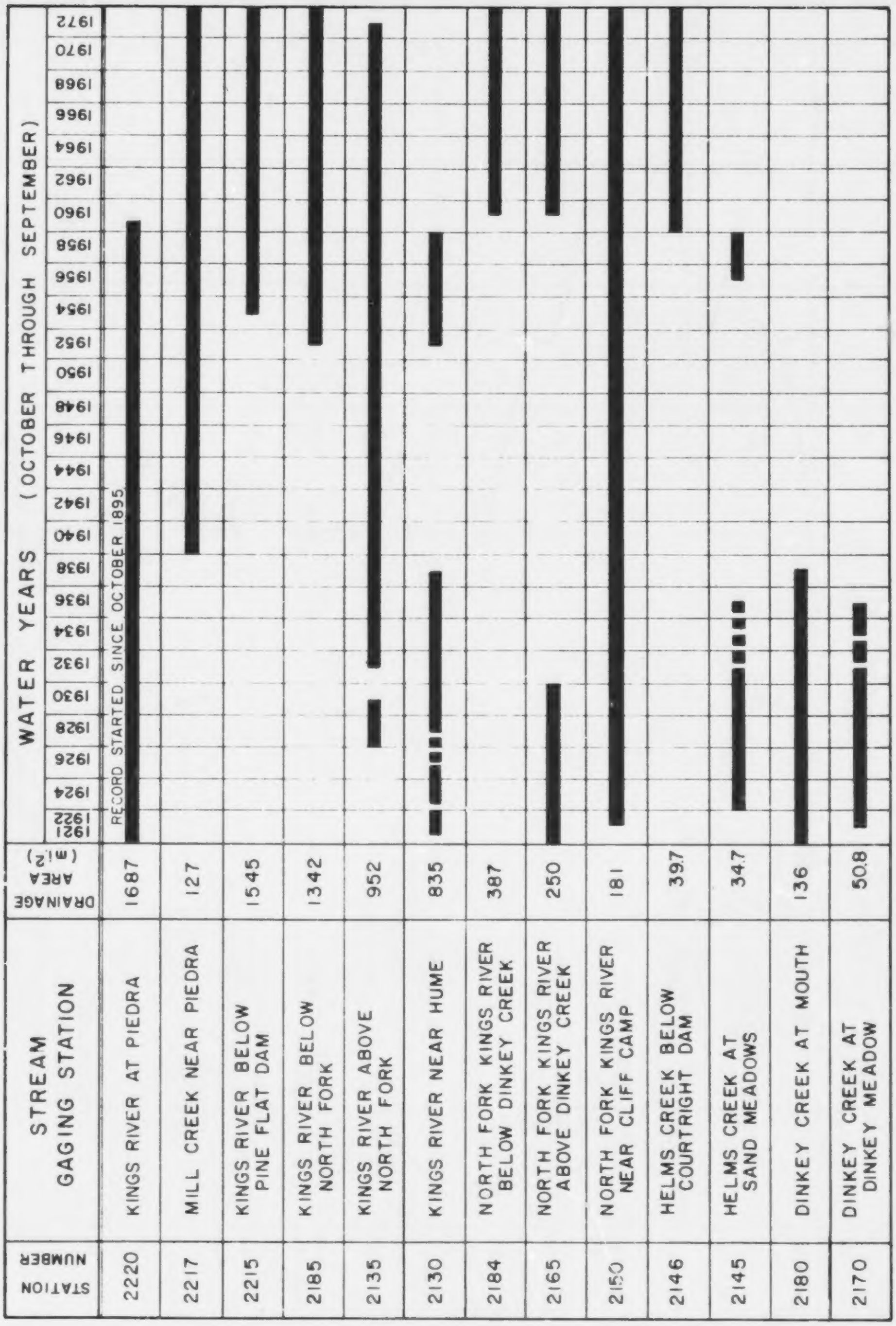


Figure 7. Records available at selected stream gauging stations in the Kings River Basin.

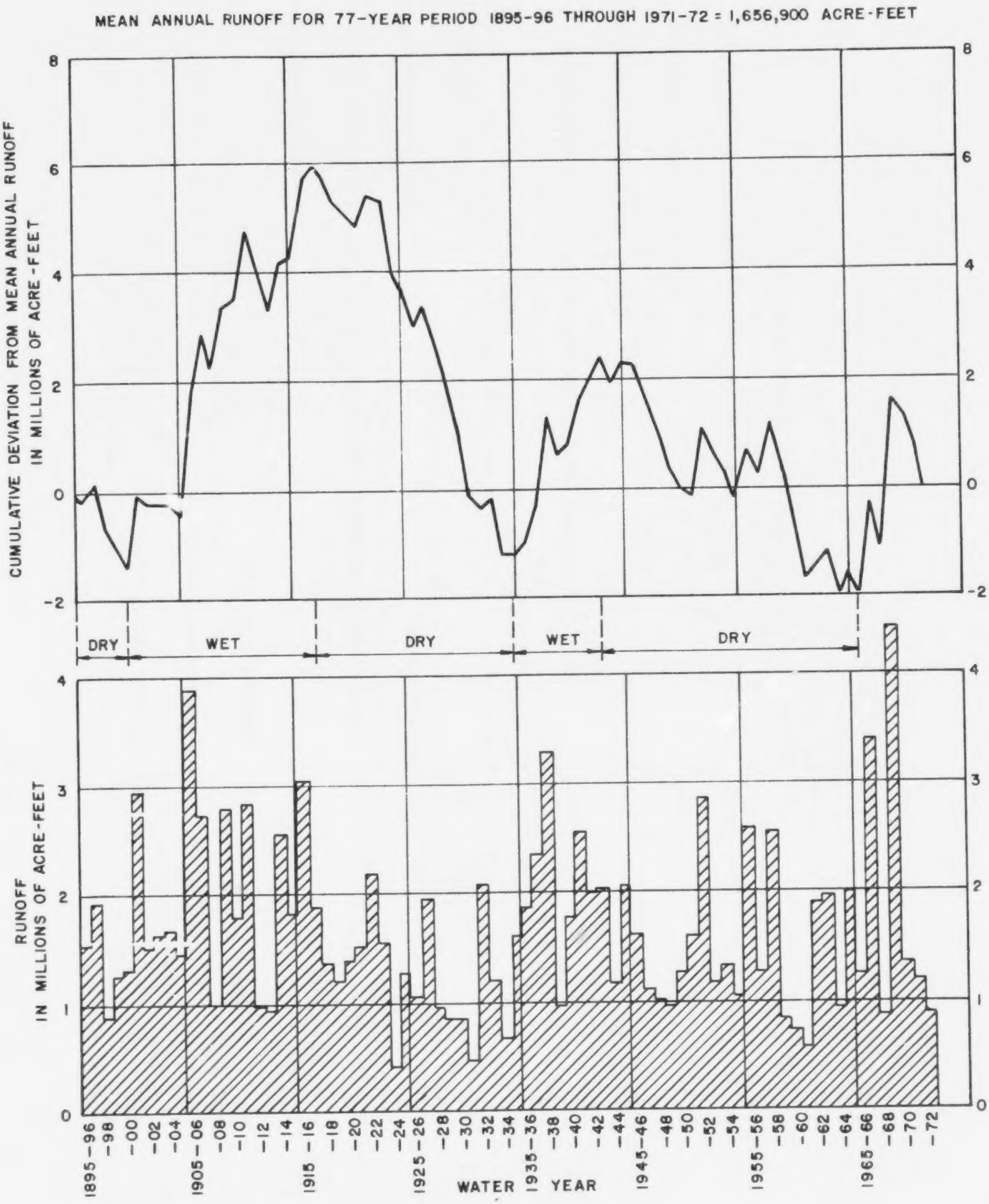


Figure 8. Wet and dry periods in the runoff in Kings River at Piedra.

TABLE 11. CLIMATIC DATA AT ASH MOUNTAIN AND GIANT FOREST--1964 (Vankat, 1974)

MONTH	Normal Mean Monthly Precipitation(inches)*		Normal Mean Monthly Temperature (°F)	
	Ash Mountain	Giant Forest	Ash Mountain	Giant Forest
January	4.55	7.85	46.2	32.0
February	4.85	8.49	49.3	33.4
March	4.28	6.88	53.0	37.3
April	3.00	4.52	59.6	42.1
May	1.17	1.90	66.0	47.8
June	0.24	0.42	74.6	55.5
July	0.05	0.12	83.4	64.0
August	0.04	0.12	81.8	63.2
September	0.21	0.35	76.6	59.2
October	0.99	1.68	66.4	49.5
November	2.19	3.70	55.3	40.5
December	4.95	8.37	48.6	34.8
Annual	26.52	44.40	63.4	46.6

* See Metric Conversion Table, Appendix A.

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APPENDIX A

METRIC CONVERSION TABLE*

Non-Metric Unit	Multiply by	Metric Unit
acre	0.40468 (one hectare = 10,000 square meters)	hectare (ha)
acre-foot	1233.48	cubic meters (m^3)
foot	0.3048	meter (m)
gallon	3.7854 (one liter = 0.001 cubic meter)	liter (1)
inch	2.54	millimeter (mm)
mile	1.609	kilometer (km)
pint	0.473	liter (1)
pound	0.453	kilogram (kg)

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* English units were used interchangeably in this report, because much of the source data were not available in metric units.

APPENDIX B. SPECIES LIST* -- YELLOWSTONE NATIONAL PARK

I. VEGETATION

Dicranaceae
Ceratodon purpureus

Bryoceae
Bryum Turbinalum

Equisetaceae
Equisetum arvense
Equisetum arvense, var. alpestre
Equisetum hiemale
Equisetum laevigatum
Equisetum variegatum

Selaginellaceae
Selaginella densa

Pinaceae
Abies lasiocarpa
Juniperus communis
Juniperus scopulorum
Picea engelmanni
Picea glauca
Picea pungens
Pinus albicaulis
Pinus contorta
Pinus flexilis
Pseudotsuga menziesii

Typhaceae
Typha latifolia

Sparganiaceae
Sparganium androcladum

Najadaceae
Potamogeton alpinus
Potamogeton filiformis
Potamogeton gramineus
Potamogeton natans
Potamogeton nodosus
Potamogeton strictifolius
Potamogeton tenuifolius

Alismaceae
Sagittaria arifolia

Gramineae
Agropyron albicans
Agropyron caninum
Agropyron dasystachyum
Agropyron spicatum
Agropyron subsecundum
Agropyron trachycaulum

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*Except where noted, species lists were based on U.S. Park Service lists.

Bouteloua

Agrostis alba
Agrostis exarata
Agrostis hiemalis
Alopecurus aequalis
Beckmannia syzigachne
Bromus anomalus
Bromus carinatus
Bromus ciliatus
Bromus commutatus
Bromus inermis
Bromus tectorum
Calamagrostis canadensis
Calamagrostis inexpansa
Calamogrostis rubescens
Dactylis glomerata
Danthonia intermedia Vasey
Deschampsia caespitosa
Elymus anerecis
Elymus condensatus
Elymus glaucus
Festuca idahoensis
Glyceria borealis
Glyceria elata
Glyceria pauciflora
Glyceria striata
Hersperochloa kingii
Hierochloe odorata
Hordeum brachyantherum
Hordeum jubatum
Koeleria cristata
Melica spectabilis
Muhlenbergia andina
Muhlenbergia filiformis
Muhlenbergia racemosa
Muhlenbergia richardsonis
Orhyzopsis hymenorden
Phalaris arundinacea
Phleum pratense
Panicum thermale
Poa annua
Poa canbyi
Poa fendleriana
Poa interior
Poa leptocoma
Poa nervosa
Poa palustris
Poa pratensis
Sitanion hystrix
Sphenopholis obtusata
Stipa columbiana
Stipa comata
Stipa lettermanni
Stipa occidentalis
Stipa richardsoni
Trisetum spicatum
Trisetum wolfii

Cyperaceae

Carex aquatilis
Carex arthrostachya
Carex aurea
Carex chimaphila
Carex concinnocdes
Carex douglasii
Carex eastwoodiana
Carex festivells
Carex geyeri
Carex gravida

Cyperaceae (continued)

Carex hoodii
Carex interior Bailey
Carex lanuginosa Michx
Carex nebraskensis
Carex occidentalis
Carex phaeocephala
Carex rossii
Carex rostrata
Carex vesicaria
Eleocharis acicularis
Eleocharis macrostachya
Eleocharis obtusa
Eleocharis pauciflora
Scirpus subterminalis

Lemnaceae

Lemna minor
Lemna trisulca

Juncaceae

Juncus balticus
Juncus bufonius
Juncus confusus
Juncus ensifolius
Juncus filformis
Juncus longistylis
Juncus parryi
Juncus saximontanus

Liliaceae

Allium spp.
Allium brevistylum
Allium textile
Brodiaea douglasii
Camassia quamash
Erythronium grandiflorum
Fritillaria atropurpurea
Fritillaria pudica
Sesporum trachycarpum
Smilacina stellata
Smilacina racemosa
Streptopus amplexifolius
Zygadenus paniculatus
Zygadenus elegans

Iridaceae

Sisyrinchium idahoense

Orchidaceae

Calypso bulbosa
Corallorhiza mertensiana
Corallorhiza striata
Goodyera oblongifolia
Habenaria hyperborea
Habenaria unalascensis
Spiranthes romanzoffiana

Salicaceae

Populus angustifolia
Populus balsamifera
Populus tremuloides
Salix caudata
Salix drummondiana var. subcoerulea
Salix exigua
Salix farrae
Salix geyeriana
Salix luted
Salix luted var. platyphylla

Salicaceae (continued)

Salix mackenziana
Salix melanopsis
Salix melanopsis var. tenerrima
Salix pseudocordata var. aequalis
Salix scouleriana
Salix wolfii
Salix wolfii var. idahoensis

Betulaceae

Alnus tenuifolia
Betula glandulosa

Cannabinaceae

Humulus lupulus

Urticaceae

Urtica gracilis

Santalaceae

Comandra pallida

Loranthaceae

Arceuthobium americanum

Polygonaceae

Eriogonum heracleoides
Eriogonum subalpinum
Eriogonum umbellatum
Pachistima myrsinites
Polygonum amphibium
Polygonum aviculare
Polygonum bistortoides
Polygonum buxiforme
Polygonum douglasii
Polygonum fluitans
Rumex acetosella
Rumex crispus
Rumex fueginus
Rumex paucifolius
Rumex triangulivalvis

Chenopodiaceae

Blitum capitatum
Chenopodium album
Chenopodium aridum
Eurotia lanata
Kochia scoparia
Monolepis nuttalliana
Salsola pestifer
Sarcobatus spp.

Portulacaceae

Claytonia lanceolata

Caryophyllaceae

Arenaria congesta
Arenaria lateriflora
Cerastium oreophilum
Sagina saginoides
Spergularia rubra
Stellaria americanum
Stellaria longifolia
Stellaria longipes Goldie

Nympharceae

Nuphar polysepalum

Ranunculaceae

Aconitum columbianum
Actaea rubra
Anemone globosa
Aquilegia caerulez
Clematis columbiana
Clematis eriophora
Delphinium nelsoni Greene
Delphinium occidentale
Ranunculus acriformis var. montanensis
Ranunculus aquatilis var. capilaceus
Ranunculus cymbalaria
Ranunculus glaberrimus
Ranunculus inamoenus
Ranunculus natans
Ranunculus sceleratus var. multifidus
Thalictrum fendleri
Thalictrum occidentale
Thalictrum sp.

Berberidaceae

Berberis repens
Mahonia aquifolium

Cruciferae

Arabis drummondii
Arabis exilis
Arabis glabra
Arabis hirsuta
Arabis holboellii
Arabis nuttallii
Barbarea americana
Capsella bursa-pastoris
Cardamine breweri
Descurainia pinnata
Descurainia sophia
Draba stenoloba
Erysimum cheiranthoides
Lepidium campestre
Lepidium densiflorum var. bourgeauanum
Lepidium perfoliatum
Lesquerella prostrata
Rorippa palustris
Thlaspi arvense
Thlaspi parvilflorum

Crassulaceae

Sedum debile
Sedum lanceolatum
Sedum stenopetalum

Saxifragaceae

Heuchera parviflora
Lithophragma bulbifera
Lithophragma parviflora
Parnassia parviflora
Saxifraga montanensis
Saxifraga punctata var. arguta
Saxifraga rhomboidea

Grossulariaceae

Ribes cereum
Ribes inerme
Ribes lacustre
Ribes sativum
Ribes setosum
Ribes viscosissimum
Ribes montigenun

Rosaceae

Amelanchier alnifolia
Fragaria bracteata
Fragaria glauca
Fragaria pauciflora
Fragaria platypetala
Fragaria vesea
Fragaria virginiara
Geum macrophyllum
Geum triflorum
Physocarpus malvaceus
Potentilla arguta spp. convallaria
Potentilla arguta spp. typica
Potentilla diversifolia
Potentilla flabelliformis
Potentilla fruticosa
Potentilla gracilis spp. nutallii
Potentilla monspeliensis
Potentilla pulcherrima
Prunus melanocarpa
Prunus virginiana
Purshia tridentata
Rosa acicularis
Rosa fendleri
Rosa woodsii
Rubus parviflorus
Rubus strigosus
Sieversia ciliata
Sorbus scopulina
Spiraea betulifolia
Spiraea lucida

Cactoceae

Astragalus adsurgens Leguminosae
Astragalus agrestis
Astragalus alpinus
Astragalus bodini
Astragalus decumbens var. oblongifolius
Astragalus glareosus
Astragalus miser
Caragana arborescens
Glycyrrhiza lepidota
Hedysarum boreale var. cinerascens
Lupinus argenteus
Lupinus humicola
Lupinus lepidus spp. caespitosus
Lupinus leucophyllus
Lupinus parviflorus
Medicago lupulina
Medicago sativa
Melilotus alba
Melilotus officinalis
Opuntia polyocantha
Oxytropis deflexa
Trifolium hybridum
Trifolium pratense
Trifolium repens
Trifolium rydbergii
Vicia americana var. linearis

Linaceae

Linum lewisii
Linum perenne

Geraniaceae

Geranium nervosum
Geranium richardsonii
Geranium viscosissimum

Callitrichaceae

Callitriche palustris

Limnanthaceae

Floerkia occidentalis

Celastraceae

Pachystima myrsinites

Pyrolaceae

Pyrola asarifolia
Pyrola secunda

Acreraceae

Acer glabrum
Acer grandidentata

Rhamnaceae

Ceanothus velutinus
Rhamnus alnifolia

Malvaceae

Sphaeralcea rivularis

Violaceae

Viola adunca
Viola canodensis
Viola nephrophylla

Elaeagnaceae

Elaeagnus commutata
Shepherdia canadensis

Onagraceae

Epilobium adenocaulon
Epilobium angustifolium
Epilobium latifolium
Epilobium paniculatum
Epilobium saximontanum
Epilobium suffruticosum
Gayophytum diffusum
Oerothera herteranthera

Haloragidaceae

Hippuris vulgaris
Myriophyllum verticillatum
Myriophyllum exalbescens

Umbelliferae

Angelica pinnata
Berula erecta
Bupleurum americanum
Heracleum lanatum
Ligusticum filicinum
Lomatium ambiguum
Lomatium dissectum
Lomatium simplex
Osmorhiza chilensis
Osmorhiza depauperata
Osmorhiza obtusa
Osmorhiza occidentalis
Perideridia bolanderi
Perideridia gairdneri
Sium suave

Cornaceae

Cornus stolonifera

Ericaceae

Arctostaphylos uva-ursi
Chimaphila umbellata
Menziesia ferruginea
Pterospora andromeda
Pyrola asarifolia
Pyrola chlorantha
Pyrola secunda
Vaccinium membranaceum
Vaccinium scoparium
Vaccinium globulare

Primulaceae

Androsace septentrionalis var. puberulenta
Androsace septentrionalis var. subumbellata
Dodecatheon pauciflorum
Frosera speciosa

Gentiancaceae

Gentiana amarella
Gentiana thermalis
Swetia radiata

Polemoniaceae

Collomia linearis
Gilia aggregata
Linanthus septentrionalis
Phlox longifolia
Phlox multiflora
Polemonium caeruleum var. occidentalis
Polemonium pulcherrimum

Hydrophyllaceae

Hydrophyllum capitatum
Nemophila breviflora
Phacelia franklinii
Phacelia heterophylla
Phacelia leucophylla
Phoulia hostata

Boraginaceae

Cryptantha affinis
Hackelia diffusa var. caerulescens
Hackelia floribunda
Lappula cenchroides
Lappula foliosa
Lithospermum ruderale
Myosolis arvensis

Labiatae

Agastache urticifolia
Dracocephalum parviflorum
Mentha canadensis
Prunella vulgaris
Scutellaria galericulata

Scrophulariaceae

Castilleja flava
Castilleja lineariaefolia
Castilleja longispica
Castilleja lutea
Castilleja miniata
Castilleja rhexifolia
Collinsia parviflora
Cordylanthus ramosus
Mimulus guttatus
Orthocarpus luteus
Pedicularis groenlandica
Pedicularis paysoniana

Scrophulariaceae (continued)

Penstemon aridis
Penstemon deustus
Penstemon procerus
Penstemon subglaber
Veronica americana
Veronica peregrina
Veronica serpyllifolia

Orobanchaceae

Orobanche fasciculata
Orobanche ludoviciana
Orobanche uniflora

Lentibulariaceae

Utricularia vulgaris

Plantaginaceae

Plantago lanceolata
Plantago major

Rubiaceae

Galium bifolium
Galium boreale
Galium trifidum

Caprifoliaceae

Linnaea borealis var. americana
Lonicera involucrata
Lonicera utahensis
Sambucus melanocarpa
Symphoricarpos albus
Symphoricarpos occidentalis
Symphoricarpos oreophibes
Symphoricarpos rivularis
Symphoricarpos tetonensis
Valeriana dioica

Valerianaceae

Valeriana obovata
Valeriana occidentalis

Campanulaceae

Campanula rotundifolia

Lobeliaceae

Porterella carnosula

Compositae

Achillea millefolium
Agoseris elata
Agoseris glauca
Agoseris glauca var. laciniata
Agoseris purpurea
Antennaria aprica
Antennaria arida
Antennaria corymbosa
Antennaria dimorpha
Antennaria lanata
Antennaria luzuloides
Antennaria parvifolia
Antennaria racemosa
Antennaria rosea
Arnica chamissonis
Arnica cordifolia
Arnica latifolia
Artemisia abrotanum
Artemisia cana

Compositae (continued)

Artemisia dracunculoides
Artemisia ludoviciana
Artemisia tridentata
Artemisia tripartita
Aster campestris
Aster canescens
Aster chilensis
Aster coerulescens var. laetevirens
Aster conspicuus
Aster engelmonnii
Aster foliaceus var. apricus
Aster foliaceus var. frondeus
Aster integrifolius
Aster occidentalis
Aster parelegans
Balsamorrhiza sagittata
Besseya wyomingensis
Chaenactis douglasii
Chrysopsis villosa
Chrysothamus nauseosus
Chrysothamus viscidiflaces
Cirsium arvense
Cirsium drummondii
Cirsium uniutalum
Conyza canadensis
Crepis acuminata
Crepis intermedia
Crepis tectorum
Crepis alrabarba
Crepis atrabarba
Erigeron divergens
Erigeron peregrinus
Erigeron glabellus
Erigeron spp.
Erigeron ochroleucus
Erigeron pumilus spp. concinnoides
Erigeron speciosus
Eriophyllum lanatum
Gnaphalium chilense
Gnaphalium palustre
Grindelia squarrosa
Haplopoppus acaulis
Helionthella uniflora
Helionthella quinquenervis
Hieracium albiflorum
Hieracium cynoglossoides
Hieracium scouleri
Iva zanthifolia
Lactuca integrata
Machaeranthera pulverulenta
Machaeranthera viscosa
Madia glomerata
Matricaria suaveolens
Rudbeckia occidentalis
Senecio crassulus
Senecio cymbalariodes
Senecio glaucescens
Senecio hydrophilus
Senecio perplexus
Senecio streptanthifolus
Senecio serra
Solidago lepida var. elongata
Solidago lepida var. fallax
Solidago multirodiata
Solidago missouriensis
Solidago nemoralis
Stephanomeria tenuifolia
Tanacetum vulgare

Compositae (continued)

Taraxacum officinale
Tetradymia inermis
Tragopogon porrifolius
Viguiera mutiflora
Wyethia helianthoides

Apocynaceae

Apocunum androsaemifolium

II. INSECTS (Vincent, 1967)

Coleopters (Order)

Diptera (Order)

Antocha spp.
Atherix spp.
Cinygmula sp.
Ephemerella hystirix
Glossosoma spp.
Hexatema spp.
Hexatone spp.
Rhittrogenia hageni
Simulium spp.

Ephemeropters (Order)

Plecoplera (Order)

Acroneuria pacifica
Acroneuria theodora
Acrynopteryx spp.
Alloperla spp.
Claassenia sabulosa
Isoperla spp.
Leutra spp.
Nemoura spp.
Pteronarcys california

Trichoptera (Order)

Arctopsyche grandis
Dolophiledes spp.
Glossosoma spp.
Rhyacophila spp.
Rhyarophila airopedes

Ephydra lamproscatella
Paracoenia turbida
Partnuniella thermalis
Pteromalidae Urolepis

III. FISHES

Native Fishes:

Catostomus ardens (Utah Sucker)
Catostomus catostomus (Longnose Sucker)
Catostomus platyrhynchus (Mountain Sucker)
Cottus bairdii (Mottled Sculpin)
Gila atraria (Utah Chub)
Prosopium williamsoni (Mountain Whitefish)
Rhinichthys cataractae (Longnose Dace)
Rhinichthys osculus (Speckled Dace)
Richardsonius balteatus (Redside Shiner)
Richardsonius balteatus x Rhinichthyes osculus (Redside Shiner x Speckled Dace Hybrid)
Salmo Clarki (Cutthroat Trout)
Thymallus arcticus (Arctic Grayling, American)

Introduced Fishes:

Couesius plumbeus (Lake Chub)

Salmo gairdneri (Rainbow Trout)

Salmo gairdneri x Salmo Clarkii (Rainbow x Cutthroat Trout Hybrid)

Salmo trutta (Brown Trout)

Salvelinus fontinalis (Brook Trout)

Salvelinus namayrush (Lake Trout)

IV. BIRDS

Acanthis flammea	(Common Redpoll)
Accipiter cooperii	(Cooper's Hawk)
Accipiter gentilis	(Goshawk)
Accipiter striatus	(Sharp-shinned Hawk)
Actitis macularia	(Spotted Sandpiper)
Aechmophorous occidentalis	(Western Grebe)
Aegolius acadicus	(Saw-whet Owl)
Aegolius funereus	(Boreal Owl)
Aëronautes saxatalis	(White-throated Swift)
Agelaius phoenicieus	(Red-winged Blackbird)
Aix sponsa	(Wood Duck)
Ammodramus savanarium	(Grasshopper Sparrow)
Anas acuta	(Pintail)
Anas carolinensis	(Green-winged Teal)
Anas cyanoptera	(Cinnamon Teal)
Anas discors	(Blue-winged Teal)
Anas platyrhynchos	(Mallard)
Anas strepera	(Gadwall)
Anthus spinoletta	(Water Pipit)
Aquila chrysaëtos	(Golden Eagle)
Ardea herodias	(Great Blue Heron)
Asio flammeus	(Short-eared Owl)
Asio otus	(Long-eared Owl)
Asyndesmus lewis	(Lewis' Woodpecker)
Aythya affinis	(Lesser Scaup)

BIRDS (continued)

Aythya americana	(Redhead)
Aythya collaris	(Ring-necked Duck)
Aythya valisineria	(Canvasback)
Bombycilla cedrorum	(Cedar Waxwing)
Bombycilla garrulus	(Bohemian Waxwing)
Bonasa umbellus	(Ruffed Grouse)
Botaurus lentiginosus	(American Bittern)
Branta canadensis	(Canada Goose)
Bubo virginianus	(Great Horned Owl)
Bucephala albeola	(Bufflehead)
Bucephala clangula	(Common Goldeneye)
Bucephala islandica	(Barrow's Goldeneye)
Buteo jamaicensis	(Red-tailed Hawk)
Buteo lagopus	(Rough-legged Hawk)
Buteo regalis	(Ferruginou's Hawk)
Buteo swainsoni	(Swainson's Hawk)
Calamospiza melanocorys	(Lark Bunting)
Calcarius lapponicus	(Lapland Lockspur)
Canachites canadensis	(Spruce Grouse)
Capella gallirago	(Common Snipe)
Carpodacus cassinii	(Cassin's Finch)
Cathartes aura	(Turkey Vulture)
Catharus fuscescens	(Veery)
Catharus guttata	(Hermit Thrush)
Catharus ustulatus	(Swainson's Thrush)
Catoptrophorous semipalmatus	(Willet)
Centrocercus urophasianus	(Sage Grouse)
Certhia familiaris	(Brown Creeper)
Charadrius vociferus	(Killdeer)
Chen hyperborea	(Snow Goose)
Chlidonias niger	(Black Tern)
Chlorura chlorura	(Green-tailed Towhee)
Chondestes grammacus	(Lark Sparrow)
Chordeiles minor	(Common Nighthawk)

BIRDS (continued)

Cinclus mexicanus	(Dipper)
Circus cyaneus	(Marsh Hawk)
Colartes spp.	(Common Flicker)
Contopus sordidulus	(Western Wood Peewee)
Corvus brachyrynchos	(Common Crow)
Corvus corax	(Common Raven)
Crocethia alba	(Sanderling)
Cyanocitta stelleri	(Steller's Jay)
Dendragapus obscurus	(Blue Grouse)
Dendrocopos pubescens	(Dowry Woodpecker)
Dendrocopos villosus	(Hairy Woodpecker)
Dendroica auduboni auduboni	(Yellow-rumped Warbler)
Dendroica petechia	(Yellow Warbler)
Dendroica townsendi	(Townsend's Warbler)
Dolichonyx oryzivorous	(Bobolink)
Dumetella carolinensis	(Catbird)
Egretta thula	(Snowy Egret)
Empidonax difficilis	(Western Flycatcher)
Empidonax hammondii	(Hammond's Flycatcher)
Empidonax oberholseri	(Dusky Flycatcher)
Eremophila alpestris	(Horned Lark)
Erolia bairdii	(Baird's Sandpiper)
Erolia melanotos	(Pectoral Sandpiper)
Erolia minutilla	(Least Sandpiper)
Euphagus cyanocephalus	(Brewer's Blackbird)
Eupoda montana	(Mountain Plover)
Falco columbarius	(Merlin)
Falco mexicanus	(Prairie Falcon)
Falco peregrinus	(Peregrine Falcon)
Falco spaverius	(American Kestrel)
Fulica americana	(American Coot)
Gavia Immer	(Common Loon)
Geothypis trichas	(Common Yellowthroat)
Glaucidium gnoma	(Pygmy Owl)

BIRDS (continued)

Grus canadensis	(Sandhill Crane)
Gymnorhinus cyanocephalus	(Piñon Jay)
Haliaeetus leucocephalus	(Bald Eagle)
Hesperiphona vespertina	(Evening Grosbeak)
Hirundo rustica	(Barn Swallow)
Histrionicus histrionicus	(Harlequin Duck)
Hydroprogne caspia	(Caspian Tern)
Icterus spp.	(Northern Oriole)
Iridoprocne bicolor	(Tree Swallow)
Junco spp.	(Dark-eyed Junco)
Lanius excubitor	(Northern Shrike)
Lanius ludovicianus	(Loggerhead Shrike)
Larus californicus	(California Gull)
Larus delawarensis	(Ring-bill Gull)
Larus philadelphia	(Bonaparte's Gull)
Larus pipixcan	(Franklin's Gull)
Leucosticte atrata	(Black Rosy Finch)
Leucosticte tephrocotis	(Gray-crowned Rosy Finch)
Limosa fedoa	(Marbled Godwit)
Lobipes lobatus	(Northern Phalarope)
Lophodytes cucullatus	(Hooded Merganser)
Loxia curvirostra	(Red Crossbill)
Loxia leucoptera	(White-winged Crossbill)
Mareca Americana	(American Widgeon)
Megacryle alcyon	(Belted Kingfisher)
Mergus merganser	(Common Merganser)
Mergus serrator	(Red-breasted Merganser)
Melospiza lincolnii	(Lincoln Sparrow)
Melospiza melodia	(Song Sparrow)
Molothrus ater	(Brown-headed Cowbird)
Myadestes towsendi	(Townsend's Solitaire)
Nucifraga columbiana	(Clark's Nutcracker)
Numenius americanus	(Long-bill Curlew)
Nuttallornis borealis	(Olive-sided Flycatcher)

BIRDS (continued)

Nycticorax nycticorax	(Black-crowned Night Heron)
Olor buccinator	(Trumpeter Swan)
Olor columbianus	(Whistling Swan)
Oporornis tolmiei	(MacGillivray's Warbler)
Oreoscoptes montanus	(Sage Thrasher)
Otus asio	(Screech Owl)
Oxyura jamaicenses	(Ruddy Duck)
Pandion haliaetus	(Osprey)
Parus atricapillus	(Black-capped Chickadee)
Parus gambeli	(Mountain Chickadee)
Passer domesticus	(House Sparrow)
Passerculus sandwichensis	(Savannah Sparrow)
Passerella iliaca	(Fox Sparrow)
Passerina amoena	(Lazuli Bunting)
Pelecanus erythrorhynchos	(White Pelican)
Perdix perdix	(Gray Partridge)
Perisoreus canadensis	(Gray Jay)
Petrochelidon pyrrhonota	(Cliff Swallow)
Phalacrocorax auritus	(Double-crested Cormorant)
Pheucticus melanocephalus	(Black-headed Grosbeak)
Pica Pica	(Black-billed Magpie)
Picoides arcticus	(Black-back Three-toed Woodpecker)
Picoides tridactylus	(Northern Three-toed Woodpecker)
Pinicola enucleator	(Pine Grosbeak)
Pipilo erythrophthalmus	(Rufous-sided Towhee)
Piranga ludoviciana	(Western Tanager)
Plectrophenzx nivalis	(Snow Bunting)
Podiceps auritus	(Horned Grebe)
Podiceps caspicus	(Eared Grebe)
Podilymbus podiceps	(Pied-billed Grebe)
Pooecetes gramineus	(Vesper Sparrow)
Porzana carolina	(Sora)
Recurvirostra americana	(American Avocet)
Regulus calendula	(Ruby-crowned Kinglet)

BIRDS (continued)

Regulus satrapa	(Golden-crowned Kinglet)
Riparia riparia	(Bank Swallow)
Rynchophanes mccownii	(McCown's Longspur)
Salpinctes obsoletus	(Rock Wren)
Sayornis saya	(Say's Phoebe)
Seiurus noveboracensis	(Northern Waterthrush)
Selasphorus platycercus	(Broad-tailed Hummingbird)
Selasphorus rufus	(Rufous Hummingbird)
Setophaga ruticilla	(American Redstart)
Sialia currucoides	(Mountain Bluebird)
Sitta canadensis	(Red-breasted Nuthatch)
Sitta carolinensis	(White-breasted Nuthatch)
Sitta pygmaea	(Pygmy Nuthatch)
Spatula clypeata	(Northern Shoveler)
Spectyta cunicularia	(Burrowing Owl)
Sphyrapicus thyroideus	(Williamson's Sapsucker)
Sphyrapicus varius	(Yellow-billed Sapsucker)
Spirus pinus	(Pine Siskin)
Spinus tristis	(American Goldfinch)
Spizella arborea	(Tree Sparrow)
Spizella breweri	(Brewer's Sparrow)
Spizella passerina	(Chipping Sparrow)
Steganopus tricolor	(Wilson's phalarope)
Stelgidopteryx ruficollis	(Rough-winged Swallow)
Stellula calliope	(Calliope Hummingbird)
Sterna hirundo	(Common Tern)
Strix nebulosa	(Great Gray Owl)
Sturnella neglecta	(Western Meadowlark)
Sturnus vulgaris	(Starling)
Surnia ulula	(Hawk Owl)
Telmatodytes palustris	(Long-billed Marsh Wren)
Totanus flavipes	(Lesser Yellowlegs)
Totanus melanoleucus	(Greater Yellowlegs)
Trachycineta thalassina	(Violet-green Swallow)

BIRDS (continued)

Tringa solitaria	(Solitary Sandpiper)
Troglodytes aedon	(House Wren)
Turdus migratorius	(American Robin)
Tyrannus tyrannus	(Eastern Kingbird)
Tyrannus verticalis	(Western Kingbird)
Vermivora celata	(Orange-crowned Warbler)
Vireo gilvus	(Warbling Vireo)
Vireo olivaceous	(Red-eyed Vireo)
Vireo solitacius	(Solitary Vireo)
Wilsonia pusilla	(Wilson's Warbler)
Xanthocephalus xanthocephalus	(Yellow-head Blackbird)
Zonotrichia albicollis	(White-throat Sparrow)
Zonotrichia leucophrys	(White-crown Sparrow)

Accidental Species:

Agelaius tricolor	(Tri-colored Blackbird)
Anas rubripes	(Black Duck)
Casmerodius albus	(Common Egret)
Coccyzus Erythrophthalmus	(Black-billed Cuckoo)
Cypseloides niger	(Black Swift)
Denoroica striata	(Blackpoll Warbler)
Eudocimus albus	(White-faced Iois)
Grus americana	(Whooping Crane)
Limosa haemastica	(Hudsonian Godwit)
Mycteria americana	(Wood Stork)
Nyctea scandiaca	(Snowy Owl)
Oidemia nigra	(Black Scoter)
Quiscalus quiscula	(Common Grackle)
Sterna albifrons	(Least Tern)
Strix varia	(Barred Owl)
Vermivora ruficapilla	(Nashville Warbler)

V. MAMMALS

Alces alces	(Moose)

MAMMALS (continued)

Antilocapra americana	(Pronghorn - Antelope)
Bison bison	(Buffalo)
Canis latrans	(Coyote)
Canis lupus	(Gray Wolf)
Castor canadensis	(Beaver)
Cervus canadensis melsoni	(Elk - Wapiti)
Citellus armatus	(Uinta Ground Squirrel)
Citellus lateralis	(Golden-mantle Squirrel)
Clethrionomys gapperi	(Boreal Redback Vole)
Eptesicus fuscus	(Big Brown Bat)
Erethizon dorsatum	(Porcupine)
Eutamias amoenus	(Yellow Pine Chipmunk)
Eutamias minimus	(Least Chipmunk)
Eutamias umbrinus	(Uinta Chipmunk)
Felis concolor	(Mountain Lion - Cougar)
Glaucomys sabrinus	(Northern Flying Squirrel)
Gulo luscus	(Wolverine)
Lasionycterius noctivagans	(Silver-haired Bat)
Lasiurius cinereus	(Hoary Bat)
Lepus americanus	(Snowshoe Hare - varying Hare)
Lepus Townsendi	(Whitetail Jackrabbit)
Lutra canadensis	(River Otter)
Lynx canadensis	(Lynx)
Lynx rufus	(Bobcat)
Marmota flaviventris	(Yellowbelly Marmot)
Martes americana	(Marten)
Martes pennanti	(Fisher)
Mephitis mephitis	(Skunk, spotted)
Microtus montanus	(Mountain Vole)
Microtus pennsylvanicus	(Meadow Vole)
Microtus richardsoni	(Richardson Vole)
Mustela erminea	(Shorttail Weasel)
Mustela frenata	(Longtail Weasel)
Mustela vison	(Mink)

MAMMALS (continued)

Myotis evotis	(Long-ear Bat)
Myotis lucifigus	(Little Brown Bat)
Neotoma cinerea	(Bushytail Woodrat)
Ochotona princeps	(Pika - cory)
Odocoileus hemionus	(Mule Deer - Blacktail)
Odocoileus virginianus	(Whitetail Deer)
Ondatra zibethica	(Muskrat)

APPENDIX C. SPECIES LIST* -- SEQUOIA AND KINGS CANYON NATIONAL PARKS

I. VEGETATION

Anacardiacease

Rhus leucodermis
Rhus diversiloba
Rhus trilobata var. malcophylla

Apocynaceae

Apocynum androsaemifolium

Aristolochiaceae

Asarum hartivegii

Betulaceae

Corylus cornuta var. californica

Boraginaceae

Cryptantha nubigena

Calycanthacea

Calycanthus occidentalis

Caprifoliaceae

Lonicera interrupa
Symphoricarpos sp.
Symphoricarpos acutus

Caryophyllaceae

Stellaria jamesiana

Compositae

Baccharis sp.
Artemisia tridentata
Draba oligosperma
Draba densifolia
Draba breweri
Draba lemmonii
Haplopappus macronema
Hulsea algida
Adenocaulon bicolor
Hieracium albiflorum

Cornaceae

Cornus nutlallii

Cruciferae

Phoenicaulis eurycarpa

Cupressaceae

Libocedrces decurrens
Juniperus occidentalis

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*Taken from U.S. Park Service lists.

Cyperaceae

Carex lanuginosa
Carex rostrata
Carex nebrascensis
Carex festivella
Carex vicaria
Carex speclabilis
Carex subnigricans
Carex exserta
Carex helleri
Carex breweri

Ericaceae

Arctostaphylos viscider
Arctostaphylos patula
Arctostaphylos manzanita
Arctostaphylos nevadensis
Phyllodoce breweri

Fagaceae

Quercus douglassi
Quercus wislizeni
Quercus kelloggii
Quercus chrysolepis
Castamopsis sempervirens

Gramineae

Poa pratensis
Calamagrostis breweri
Calamagrostis canadensis
Trisetum wolfii
Trisetum spicatum
Festuca brachyphylla
Poa rupicola
Poa suksdorfii

Hippocastanaceae

Aesculus californica

Hydrophyllaceae

Eriodictyon californicum
Draperia systyla

Juncaceae

Luzula spicata

Lauraceae

Umbellularia californica

Leguminosae

Cercis occidentalis
Lupinus latifolius var. columbianus

Lileaceae

Yucca whipplei
Desporum hookeri
Smilacina racemosa var. amplexicaulix
Clintonia uniflora

Oleaceae

Fraxinus dipetala

Onagraceae

Epilolium obcordatum

Orchidaceae

Goodyera oblengifolia

Pinaceae

Abies concolor
Abies magnifica

Pinaceae (continued)

Pinus albicaulis
Pinus balfouriana
Pinus contorta
Pinus jeffreyii
Pinus lambertiana
Pinus monophylla
Pinus ponderosa
Tsuga mertensiana

Polemoniaceae

Polemonium exemium

Polygonaceae

Eriogonum ovalifolium
Oxyria digyna

Pteridaceae

Pteridium aquilinum var. lanuginosum

Pyrolaceae

Chemaphila umbellata var. occidentalis
Pyrola picta
Pyrola picta spp. dentata

Rhamnaceae

Ceanothus cordulatus
Ceanothus cuneatus
Ceanothus integerrimus
Ceanothus parvifolius
Ceanothus velutinus
Cercocarpus ledifolius
Chamaebatia foliolosa
Fragaria californica
Holodiscus microphyllus
Ivesia shockleyi
Potentilla diversifolia
Rhamnus crocea
Rosa penetorum

Salicaceae

Populus fremantii
Populus tremuloides
Populus trichocarpa
Salix orestera
Salix sp.

Saxifragaceae

Philadelphus Lewisii spp. californicus
Ribes divaricatum
Ribes roezlii
Ribes sp.

Scrophulariaceae

Castilleja nana
Penstemon davidsonii

Sterculiaceae

Fremontia california

Taxaceae

Torreya californica

Taxodiaceae

Sequoiadendron giganteum

Umbelliferae

Galium sparsiflorum

Umbelliferae (continued)

Galium triflorum

Osmorhija chilensis

Violaceae

Viola lobata

Rare and endangered plant species

Aster piersonii

Carpentaria californica

Castilleja culbertsonii

Dicentra formosa spp. nevadencis

Eriophyllum lanatum var. croceum

Ivesia argyrocoma

Lewisia congdonii

Lupinus dalesiae

Phacelia orogenes

Phalacroseris bolanderi

Raillardella Muirii

Strepanthus farnsworthianus

Strepanthus gracilis

II. FISH

Catostomus occidentalis	(Sacramento Sucker)
Mylopharodon conocephalus	(Hard Head Minnow)
Salmo aquabonita	(Golden Trout)
Salvelinus fontinalis	(Eastern Brook Trout)
Salmo gairdneri	(Rainfow Trout)
Salmo trutta	(Brown Trout)

III. AMPHIBIANS

Batrachoseps attenuatus	(California Slender Salamander)
Batrachoseps relictus	(Relictual Slender Salamander)

AMPHIBIANS (continued)

Bufo boreas	(Western Toad)
Bufo canorus	(Yosemite Toad)
Ensatina eschscholtzi	(Eschscholtz Salamander)
Hydromantes platycephalus	(Mount Lyell Salamander)
Hyla regilla	(Pacific Tree Frog)
Rana boylei	(Foothill Yellow-legged Frog)
Rana catesbeiana	(Bullfrog)
Rana muscosa	(Mountain Yellow-legged Frog)
Triturus torosa	(California Newt)

IV. REPTILES

Anniella pulchra	(California Legless Lizard)
Charina bottae	(Rubber Boa)
Clemmys marmorata	(Pond turtle)
Cnemidophorus tigris	(Western Whiptail)
Coluber constrictor	(Racer)
Contia tenuis	(Sharp-tailed Snake)
Crotalus viridis	(Western Rattlesnake)
Diadophis punctatus	(Ringneck Snake)
Eumeces gilberti	(Gilbert's Skink)
Gerrhonotus coeruleus	(Northern Alligator Lizard)
Gerrhonotus multicarinatus	(Foothill Alligator Lizard)
Hypsiglena torquata	(Spotted Snake)
Lampropeltis getulus	(Common Kingsnake)
Lampropeltis zonata	(California Mountain Kingsnake)
Masticophis lateralis	(Striped Racer)
Phrynosoma coronatum	(Coast Horned Lizard)
Pituophis melanoleucus	(Gopher Snake)
Sceloporus graciosus	(Sagebrush Lizard)
Sceloporus occidentalis	(Western Fence Lizard)
Tantilla planiceps	(Western Black-headed Snake)
Thamnophis couchi	(Western Aquatic Garter Snake)
Thamnophis elegans	(Western Terrestrial Garter Snake)

REPTILES (continued)

Thamnophis sirtalis	(Common Garter Snake)
Uta stansburiana	(Side-blotched Lizard)

V. BIRDS

Accipiter cooperii	(Cooper's Hawk)
Accipiter gentilis	(Goshawk)
Accipiter striatus	(Sharp-shinned Hawk)
Actitis macularia	(Spotted Sandpiper)
Aegolius acadicus	(Saw-whet Owl)
Aëronautes saxatalis	(White-throated Swift)
Agelaius phoeniceus	(Red-winged Blackbird)
Amphispiza belli	(Sage Sparrow)
Anas platyrhynchos	(Mallard Duck)
Aphelocoma coerulescens	(Scrub Jay)
Archilochus alexandri	(Black-chinned Hummingbird)
Ardea herodias	(Great Blue Heron)
Asyndesmus lewis	(Lewis' Woodpecker)
Bombycilla cedorum	(Cedar Waxwing)
Branta canadensis	(Canada Goose)
Bubo virginianus	(Great Horned Owl)
Buteo jamaicensis	(Red-tailed Hawk)
Calypte anna	(Anna's Hummingbird)
Carpodacus cassinii	(Cassin's Finch)
Carpodacus mexicanus	(House Finch)
Carpodacus purpureus	(Purple Finch)
Cathartes aura	(Turkey Vulture)
Catharus guttata	(Hermit Thrush)
Catharus ustulatus	(Swainson's Thrush)
Catherpes mexicanus	(Canyon Wren)
Certhia familiaris	(Brown Creeper)
Chaetura vauxi	(Vaux's Swift)
Chamaea fasciata	(Wren-tit)
Chorura chlorura	(Green-tailed Towhee)

BIRDS (continued)

Chondestes grammacus	(Lark Sparrow)
Cinclus mexicanus	(Dipper)
Colartes spp.	(Common Flicker)
Columba fasciata	(Band-tailed Pigeon)
Contopus sordidulus	(Western Wood Peewee)
Corvus corax	(Common Raven)
Cyanocitta stelleri	(Steller's Jay)
Cypseloides niger	(Black Swift)
Dendragapus obscurus	(Blue Grouse)
Dendrocopos albolarvatus	(White-headed Woodpecker)
Dendrocopos nuttallii	(Nuttall's Woodpecker)
Dendrocopos pubescens	(Downy Woodpecker)
Dendrocopos villosus	(Hairy Woodpecker)
Dendroica auduboni	(Audubon's Warbler)
Dendroica nigrescens	(Black-throated Gray Warbler)
Dendroica occidentalis	(Hermit Warbler)
Dendroica petechia	(Yellow Warbler)
Dendroica townsendi	(Townsend's Warbler)
Dryocopos pileatus	(Pileated Woodpecker)
Empidonax spp.	(Flycatchers)
Euphagus cyanocephalus	(Brewer's Blackbird)
Falco sparverius	(American Kestrel)
Glaucidium gnoma	(Pygmy Owl)
Hesperiphona vespertina	(Evening Grosbeak)
Icterus spp.	(Northern Oriole)
Iridoprocne bicolor	(Tree Swallow)
Ixoreus naevius	(Varied Thrush)
Junco spp.	(Dark-eyed Junco)
Leucosticte tephrocotis	(Gray-crowned Rosy Finch)
Lophortyx californicus	(California Quail)
Megaceryle alcyon	(Belted Kingfisher)
Melanerpes formicivorous	(Acorn Woodpecker)
Melospiza lincolnii	(Lincoln's Sparrow)
Melospiza melodia	(Song Sparrow)

BIRDS (continued)

Mimus polyglottos	(Mockingbird)
Molothrus ater	(Brown-headed Cowbird)
Myadestes townsendi	(Townsend's Solitaire)
Myiarchus cinerascens	(Ash-throated Flycatcher)
Nucifraga columbiana	(Clark's Nutcracker)
Nuttallornis borealis	(Olive-sided Flycatcher)
Oporornis tolmiei	(MacGillivray's Warbler)
Oreortyx pictus	(Mountain Quail)
Otus asio	(Screech Owl)
Otus flammeolus	(Flammulated Owl)
Parus gambeli	(Mountain Chickadee)
Parus inornatus	(Plain Titmouse)
Passer domesticus	(House Sparrow)
Passerella iliaca	(Fox Sparrow)
Passerina amoena	(Lazuli Bunting)
Petrochelidon pyrrhonota	(Cliff Swallow)
Phainopepla nitens	(Phainopepla)
Phalaenoptilus nuttallii	(Poor-will)
Pheucticus melanocephalus	(Black-headed Grosbeak)
Pinicola enucleator	(Pine Grosbeak)
Pipilo erythrophthalmus	(Rufous-sided Towhee)
Pipilo fuscus	(Brown Towhee)
Piranga ludoviciana	(Western Tanager)
Polioptila caerulea	(Blue-gray Gnatcatcher)
Psaltriparus minimus	(Bush-tit)
Regulus calendula	(Ruby-crowned Kinglet)
Regulus satrapa	(Golden-crowned Kinglet)
Salpinctes obsoletus	(Rock Wren)
Sayornis nigricans	(Black Phoebe)
Selasphorus rufus	(Rufus Hummingbird)
Selasphorus sasin	(Allen's Hummingbird)
Sialia currucoides	(Mountain Bluebird)
Sialia mexicana	(Western Bluebird)
Sitta canadensis	(Red-breasted Nuthatch)

BIRDS (continued)

Sitta carolinensis	(White-breasted Nuthatch)
Sitta pygmaea	(Pigmy Nuthatch)
Sphyrapicus ruber ruber	(Red-breasted Sapsucker)
Sphyrapicus thyroideus	(Williamson's Sapsucker)
Sphyrapicus varius	(Yellow-bellied Sapsucker)
Spinus pinus	(Pine Siskin)
Spinus psaltria	(Lesser Goldfinch)
Spizella passerina	(Chipping Sparrow)
Stelgidopteryx ruficollis	(Rough-winged Swallow)
Stellula calliope	(Calliope Hummingbird)
Strix occidentalis	(Spotted Owl)
Sturnella neglecta	(Western Meadowlark)
Sturnus vulgaris	(Starling)
Tachycineta thalassina	(Violet-green Swallow)
Thryomanes bewickii	(Bewick's Wren)
Toxostoma redivivum	(California Thrasher)
Troglodytes aedon	(House Wren)
Troglodytes troglodytes	(Winter Wren)
Turdus migratorius	(American Robin)
Tyrannus verticalis	(Western Kingbird)
Vermivora celata	(Orange-crowned Warbler)
Vermivora ruficapilla	(Nashville Warbler)
Vireo gilvus	(Warbling Vireo)
Vireo solitarius	(Solitary vireo)
Wilsonia pusilla	(Wilson's Warbler)
Zenaidura macroura	(Morning Dove)
Zonotrichia atricapilla	(Golden-crowned Sparrow)
Zonotrichia leucophrys	(White-crowned Sparrow)

Accidental Species:

Agelaius tricolor	(Tricolored Blackbird)
Aimophila ruficeps	(Rufous-crowned Sparrow)
Alectoris graeca	(Chukar (introduced)
Aquila chrysaëtos	(Golden Eagle)

BIRDS (continued)

Charadrius vociferus	(Killdeer)
Chordeiles minor	(Common Nighthawk)
Corvus brachrhynchos	(Common Crow)
Geococcyx californianus	(Roadrunner)
Gymnogyps californianus	(California Condor)
Haliaeetus leucocephalus	(Bald Eagle)
Lanius ludovicianus	(Loggerhead Shrike)
Loxia curvirostra	(Red Crossbill)
Meleagris gallopavo	(Turkey - introduced)
Pandion halidetus	(American Osprey)
Passerculus sandwichensis	(Savannah Sparrow)
Picoides arcticus	(Blackbacked 3-toed Woodpecker)
Spinus lawrencei	(Lawrence's Goldfinch)
Spizella breweri	(Brewer's Sparrow)
Strix nebulosa	(Great Cray Owl)
Vireo huttoni	(Hutton's Vireo)

VI. MAMMALS

Antrozous pallidus	(Pallid Bat)
Aplodontia rufa	(Mountain Beaver)
Bassariscus astutus	(Ringtail Cat)
Canis latrans	(Coyote)
Canis lupus	(Wolf)
Castor canadensis	(Beaver)
Citellus beecheyi	(California Ground Squirrel)
Citellus beldingi	(Belding Ground Squirrel)
Citellus lateralis	(Golden Mantled Ground Squirrel)
Dipodomys heernanni	(Heermann Kangaroo Rat)
Eptesicus fuscus	(Big Brown Bat)
Erethizon dorsatum	(Porcupine)
Euderma maculata	(Spotted Bat)
Eutamias alpinus	(Alpine Chipmunk)
Eutamias merriami	(Merriam Chipmunk)

MAMMALS (continued)

Eutamias speciosus	(Lodgepole Chipmunk)
Eutamias Umbrinus	(Uinta Chipmunk)
Felis concolor	(Mountain Lion)
Felis domesticus	(House Cat)
Glaucomys sabrinus	(Northern Flying Squirrel)
Gulo luscus	(Wolverine)
Lasionycteris noctivagans	(Silver-haired Bat)
Lasiurus borealis	(Red Bat)
Lasiurus cinereus	(Hoary Bat)
Lepus californicus	(Blacktail Jackrabbit)
Lepus townsendii	(Whitetail Jackrabbit)
Lutra canadensis	(River Otter)
Lynx rufus	(Bobcat)
Marmota flaviventris	(Yellow-belly Marmot)
Martes americana	(Marten - Pine Marten)
Martes pennanti	(Fisher)
Mephitis mephitis	(Striped Skunk)
Microtus californicus	(California vole)
Microtus longicaudus	(Long-tail vole)
Microtus montanus	(Mountain vole)
Mus musculus	(House mouse)
Mustela erminea	(Short-tail Weasel)
Mustela frenata	(Longtail Weasel)
Myotis californicus	(California Bat)
Myotis evotis	(Long-ear Bat)
Myotis lucifugua	(Little Brown Bat)
Myotis subulatus	(Small-footed Bat)
Myotis thysanodes	(Fringed Bat)
Myotis volans	(Long-legged Bat)
Myotis yumanensis	(Yuma Bat)
Neotoma cinerea	(Bushytail Woodrat)
Neotoma fuscipes	(Dusky-footed Woodrat)
Neotoma lepida	(Desert Woodrat)
Ochotona princeps	(Pika, Cony, Rock Rabbit)

MAMMALS (continued)

Odocoileus hemionus	(Mule Deer)
Ondatra zibethica	(Muskrat)
Ovis canadensis	(Bighorn Sheep)
Perognathus californicus	(California Pocket Mouse)
Peromyscus boylei	(Brush Mouse)
Peromyscus californicus	(California Mouse)
Peromyscus maniculatus	(Deer Mouse)
Peromyscus truei	(Pinyon Mouse)
Phenacomys intermedius	(Heather Vole)
Pipistrellus hesperus	(Western Pipistrelle)
Plecotus townsendi	(Western Big-ear Bat)
Procyon lotor	(Raccoon)
Reithrodontomys megalotis	(Western Harvest Mouse)
Scapanus latimanus	(California Mole)
Sciurus griseus	(Western Gray Squirrel)
Sorex obscurus	(Dusky Shrew)
Sorex ornatus	(Ornate Shrew)
Sorex palustris	(Northern Water Shrew)
Sorex trowbridgii	(Trowbridge Shrew)
Sorex vagrans	(Vagrant Shrew)
Spilogale putorius	(Spotted Skunk)
Sylvilagus audubonii	(Desert Cottontail)
Sylvilagus backmani	(Brush Rabbit)
Tadarida brasiliensis	(Mexican Freetail Bat)
Tamiasciurus douglasi	(Douglas Squirrel - Chicaree)
Taxidea taxus	(Badger)
Thomomys bottae	(Pocket Gopher)
Thomomys monticola	(Sierra Pocket Gopher)
Urocyon cinereoargenteus	(Grey Fox)
Ursus americanus	(Black Bear)
Vulpes fulva	(Red Fox)
Zapus princeps	(Western Jumping Mouse)

*U.S. GOVERNMENT PRINTING OFFICE: 1978 - 786-260/2015 Region No. 9-1